SMITH

Use of Compressed Air for Pumping Water

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THE USE OF COMPRESSED AIR FOR PUMPING WATER

...BY...

GEORGE RUSSELL SMITH

THESIS

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THIS IS TO CERTIFY THAT THE THESIS PREPARED UNDER MY SUPERVISION BY

George Russell Smith

ENTITLED The Use of Compressed Air for Pumping Water

IS APPROVED BY ME AS FULFILLING THIS PART OF THE REQUIREMENTS FOR THE DEGREE

OF Bachelor of Science in Mechanical Engineering.

L. P. Breckenridge

HEAD OF DEPARTMENT OF Mechanical Engineering.

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[illegible]

The principle of raising a column of water by the direct pressure of compressed air has been known since the sixteenth century, but the practical application of it has been made within quite recent years. In the use of air for water elevating two general methods have been employed. In one, water and air are admitted alternately, to a chamber, which is provided with suitable valves [illegible] is supplying the air, under pressure, to the lower end of a valveless riser and thus elevating the water.

An Austrian paper, the "Berg und Huttenmannische Zeitung", of December 4th. 1886 stated that the air system of water elevating was known and used in the sixteenth century. In the "Zeitschrift des Vereins Deutscher Ingenieure" of November 16th. 1895 Gerlock [illegible] that this system of water elevating was described in 1797 by Carl Emanuel Löscher, a mining engineer, of Freiberg, as an "aerostatic drainage apparatus, by means of which water can be raised several ells without any buckets or pumps". The experiments of Löscher were made by sub-merging a rising pipe for part of its length, in the water, in a tank and then blowing compressed air through a small tube into the sub-merged opening of the first pipe. The bubbles of air became mixed with the water, in the rising main and diminished its specific gravity so that the mixture of water and air was driven high above the water level in the tank by the hydrostatic pressure, and, under certain conditions was made to flow out from the riser. In 1846 an American named [illegible] made use of this same principle in raising

[illegible] from drilled wells in Pennsylvania.

The first United States patent granted for an air lift was number [illegible] dated October 9th. 1880 and issued to Mr. Joseph P. Frizell, Member of the American Society of Civil Engineers, for a "Method of Raising Water". Mr. Frizell had previously worked out a system of air compressing, by using a vertical column of water. A patent was granted to him for this on June 29th. 1878. The method employed for the air compressing will be more fully described later. The patent for a method of raising water by means of compressed air naturally followed that of using water for compressing air.

The claim allowed on the Frizell patent of 1880 was as follows: "In the art of elevating water the method of causing a column of water to ascend in a conductor by the weight of the external water, which consists in introducing a tube of the desired length to the required depth into the water to be elevated, and then injecting compressed air in the form of minute bubbles into the water at the lower end of said tube, thereby <u>aerating</u> the water, whereby a continuous stream is caused to flow upward to the point of discharge, substantially as described".

Practically the same invention as that of Mr. Frizell was made, [illegible], Prof. [illegible] Harris, of the Missouri School of Mines. While sinking the piers, for the foundation of a bridge over the Arkansas river, near Pine Bluff, Arkansas, Prof. Harris made use of compressed air for pumping out the water and sand. A 3 inch pipe 20 feet long was set vertically, with the upper end about 4 feet above the surface of the water and the lower end resting on the sand bottom at a depth

[illegible] feet. About [illegible] inches above the lower end of the large [illegible] hole was cut and a 1 inch pipe was screwed into the large [illegible] right angles to it. Into this small pipe air was forced [illegible]s of the ordinary pump and hose connections used for sup-[illegible] the air to the divers' helmet. An abundant discharge was [illegible]ed, from the top of the large pipe, which was estimated by [illegible] to contain about equal parts of sand and water. A pat-[illegible] applied for by Mr. Harris and was first refused by the [illegible] Office on the ground that Mr. [illegible]'s application had been first presented, but the final rejection was based upon the [illegible] patent, already referred to and also the patent of Cap-[illegible] [illegible] number 2[illegible],415, the last two being for hydraulic excavators.

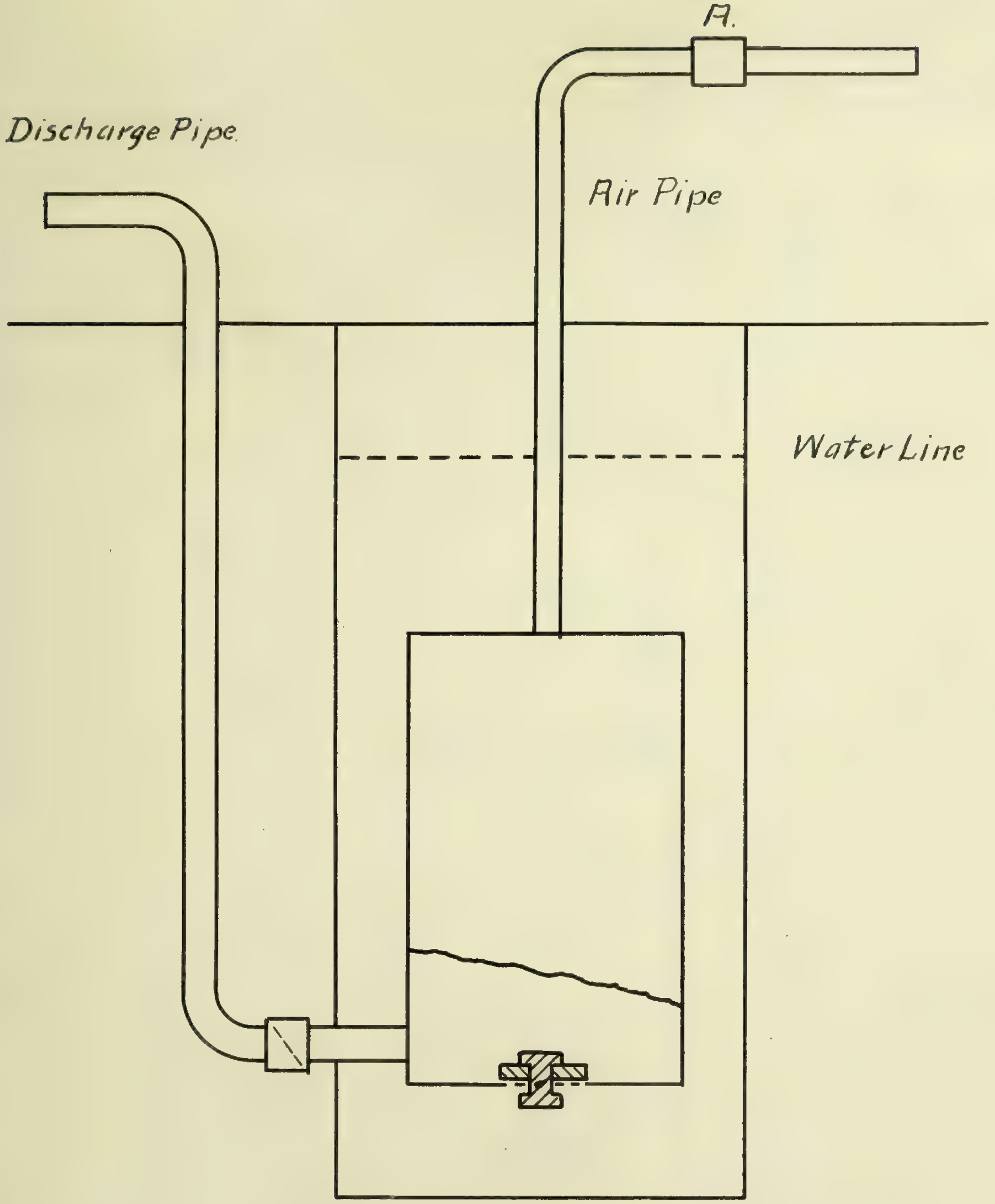
A similar invention was made by Dr. Siemens,- see abstract in [illegible] Proceedings of the Institution of Civil Engineers, volume 81, [illegible] 400, 1885 taken from "D[illegible] Polytechnische Journal" volume [illegible], page 284. In a coal shaft being sunk near Berlin, 30 meters [illegible] bearing sand had to be gone through. The shaft became [illegible]. It was attempted at first to relieve the pressure on [illegible] shaft by making numerous Abyssinian wells in the surrounding [illegible], but these owing to their small size did not permit of [illegible] Dr. Siemens, of imitating the action of gas springs, gey-[illegible], and petroleum wells, in nature. His plan was to convey compressed air to the bottom of the suction pipe and there allow [illegible] through the mass of water, where by its expansive [illegible] force would be exerted, until an equilibrium [illegible] pressure was obtained. The experiment was made

[illegible] Abyssinian tube well, that had been for some time in use. [illegible] diameter was 80 millimeters, depth 30 meters and it had a [illegible] 3 meters long. The tube was lengthened 9 meters at [illegible] and a lead pipe 20 millimeters in diameter, terminating [illegible] copper wind-bore with numerous small holes was put down to the bottom. This was connected with an air compressor, which was formed by reversing the action of a portable steam engine. Regarding the action of the lift Dr. Siemens says: "As soon as the pressure in the air vessel rose to three atmospheres, a current [illegible] established, the air escaped from the bottom of the suction [illegible] into the water in the well tube and rose slowly in numerous small bubbles. As each bubble exerted a pressure on the water surrounding it equivalent to that of the water it displaced, the equilibrium [illegible] [illegible] pipe, overflowing it if the water was not too high. The velocity of the water which is constant so long as the air [illegible] is kept up, depends upon the quantity of air supplied per unit of time, and the frictional resistance in the tube and suction pipe.

[illegible] this method was first used in France [illegible] raised [illegible] acid by means of it, the apparatus being known as "em- [illegible]

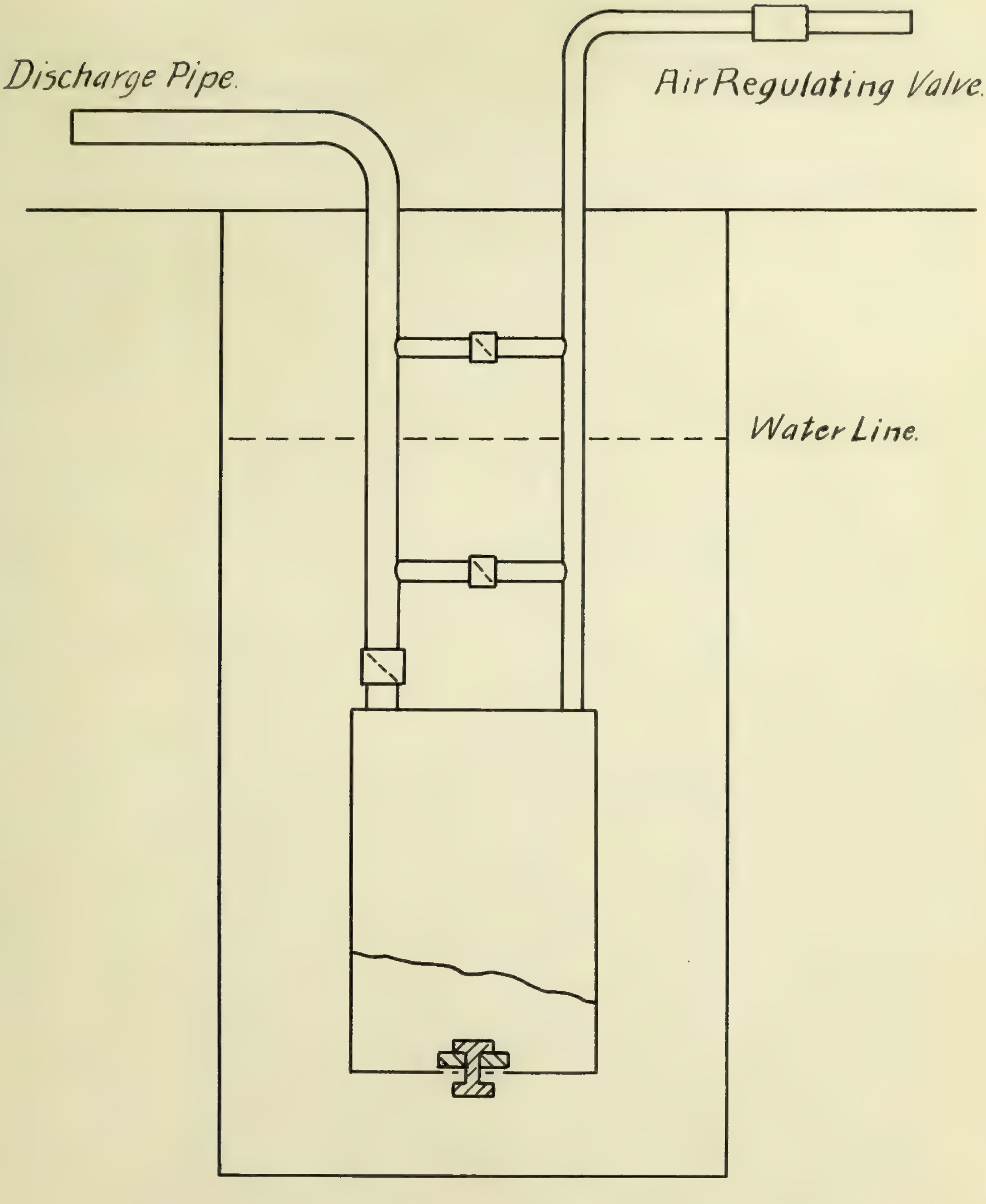
The inventor who has done most to bring the air lift pump into practical use is Dr. Julius G. Pohle. While manager of [illegible] mines Dr. Pohle discovered that in the operation of an old [illegible] pneumatic pump, an advantage was gained by introducing [illegible] air into the discharge pipe. A patent number [illegible],395 [illegible] March 23rd. 1896 to Messrs. Pohle and Hill for a form

placement alternate acting compressed air pump, in which a chamber is filled alternately with compressed air and with the water or other fluid to be elevated, the air being forced in to cause the water to ascend the discharge pipe and then allowed to escape as the chamber fills. Plate 1 shows the arrangement of the pump. The air valve at A comprises part of the patent. The valve is entirely automatic in its action, controlling the admission and escape of the air. In a second patent number 347,[illegible] issued to Frizell [illegible] August 10th, 1886, there were used, in combination with the above device, [illegible], entering the pipe at different points of its height, would ascend in bubbles through the rising liquid. Plate 2 shows the arrangement of the pump. The claim of this patent covers the combination of the ordinary displacement pump and the air lift principle. The additional air aids in elevating the water after it has left the pump. On December 6th, 1892 a patent number 48[illegible] was issued to Dr. Pohlé for "Method of Elevating Liquids". The arrangement of the apparatus is shown on plate 3. In it the air is introduced at the lower end of a vertical pipe. The quantity is sufficient to form bubbles which will expand, immediately, across the pipe and fill the bore from side to side. When the lift is started, a head or air pressure, slightly greater than that corresponding to the weight of a column of liquid, extending from the point of entrance of the gaseous fluid, to the level of the liquid surrounding the pipe, is required. Since the specific gravity of a mixture of air and liquid is less than that of the liquid alone, after the lift has started, it requires a less air pressure than that required to start it [illegible] to keep it in operation. When the lift is in full



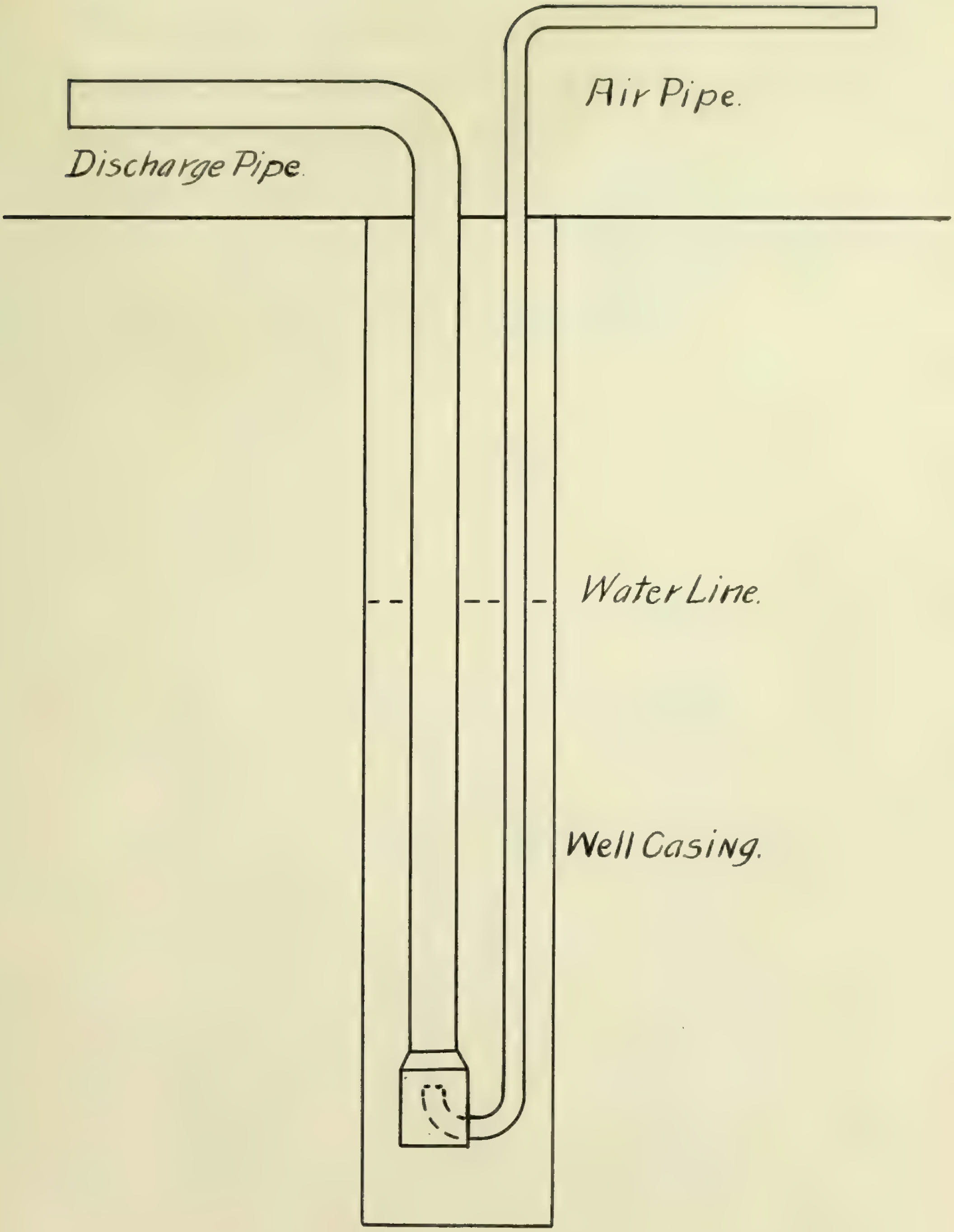
Pohlè Patent Number 338295.

Plate 1.



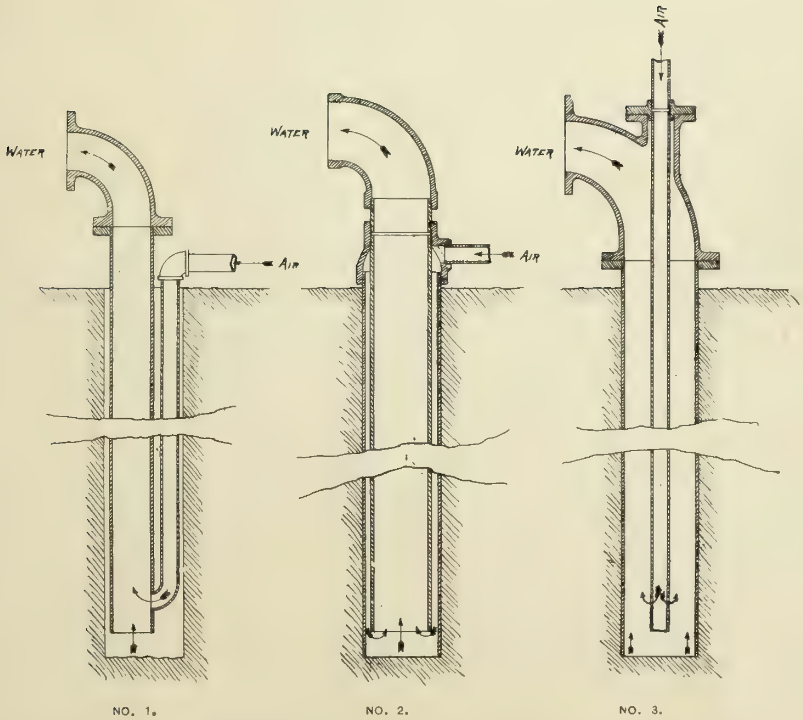
Pohle and Hill Patent. Number 347,196.

Plate 2.



Pohlė Patent, Number 487,639.

Plate 3.



THREE METHODS OF WELL PIPING.

Plate 4.

[illegible] J. [illegible], Mass., in [illegible] 18[illegible] granted patent, number 533,445 for an "Apparatus for lifting or [illegible] liquids". Claim number four of the application is as follows: "A nozzle for liquid lifting and feeding systems comprising a cylindrical body having a series of grooves forming a series of [illegible] collars, each collar provided with an upper face which is inclined with respect to the longitudinal axis of the nozzle and with a lower neutral face of greater inclination than the upper working face, and rows of inclined ports extending through said collars in lines substantially at right angles to the inclined upper working faces thereof; the lower neutral face of each collar being disposed within the lines of the jets or sprays, discharged from the next adjacent collar, substantially as and for the purposes described."

A drawing of the nozzle is given on Plate 5. It will be noticed in this that the inclination of the lower face with the longitudinal axis is greater than that of the upper axis, that the collars are slightly tapered and that the openings are at right angles to the upper face of the collars, all of these facts being claimed by the designer to be of an especial advantage.

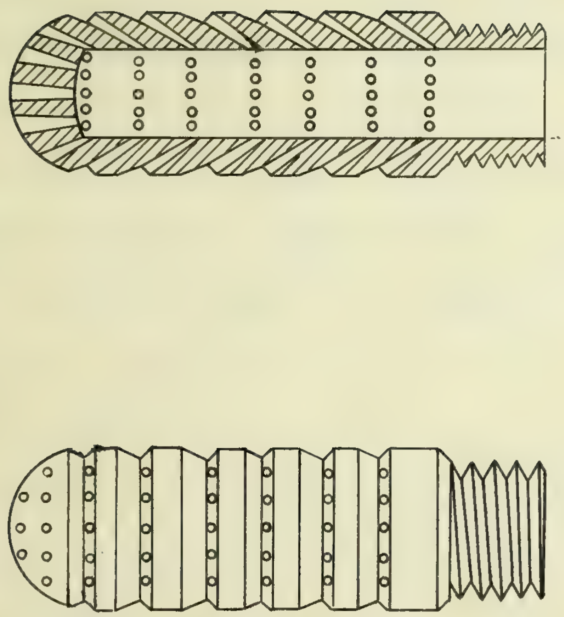


Figure 4.

Kennedy Nozzle.

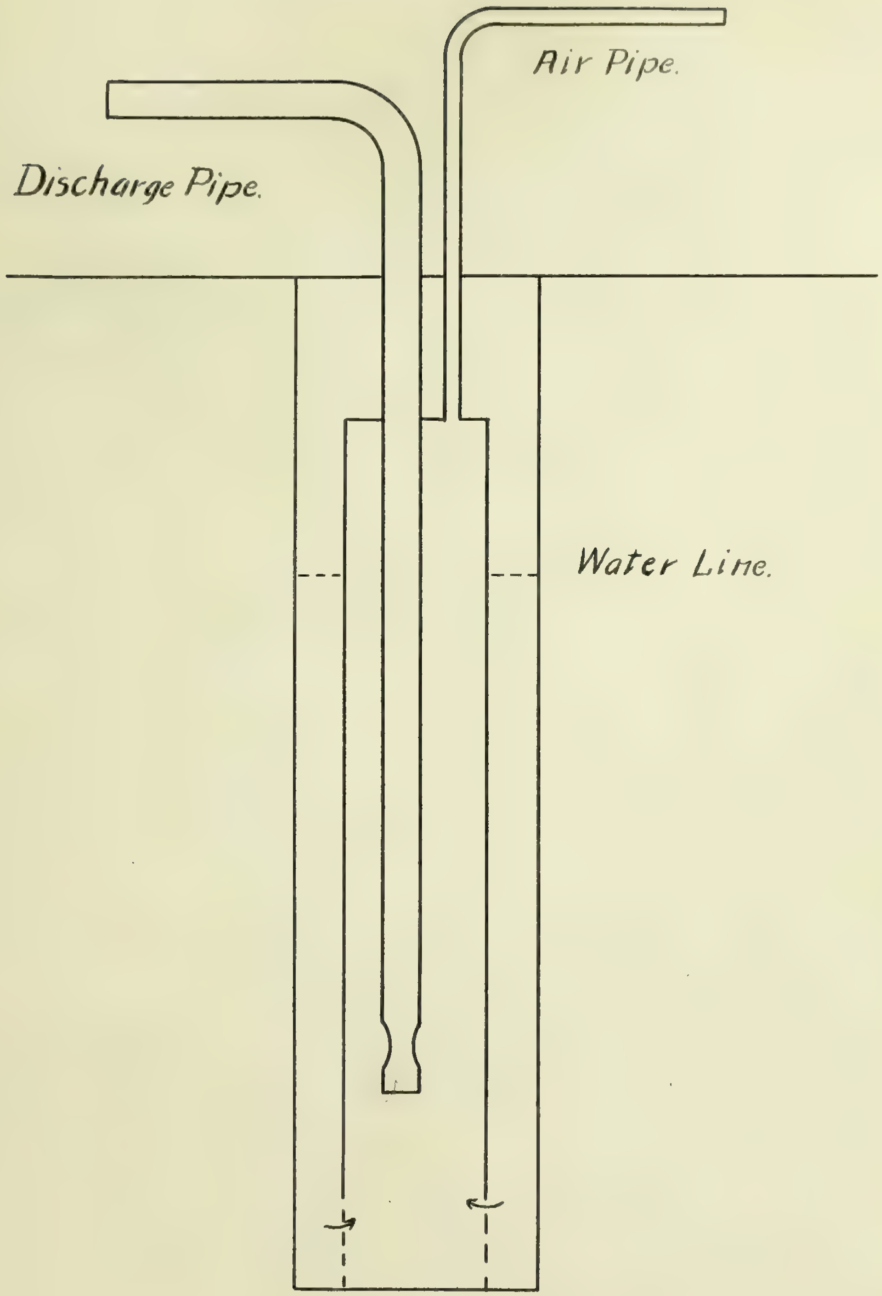
Patent Number 568,445.

Plate 5.

[illegible] W. J. [illegible] of North Plainfield, N.J. was issued [illegible] [illegible] patent Number [illegible] for an "Air Lift Pump". The [illegible] claims, taken from the patent record, which are given, to- [illegible] with Plate [illegible] fully describe the apparatus.

[illegible] 1.- The herein described method of pumping which consists [illegible] supplying, [illegible] to the open lower end of a valveless delivery pipe surrounded by an open bottom chamber continuously supplied with gas under pressure, of charges of the liquid and of [illegible] under pressure and in alternation.

Claim 7.- In an air lift pump the combination of a stationary delivery pipe formed with a contracted portion nearer its lower extremity, a pressure chamber surrounding said pipe, said chamber permanently open at its lower end to receive the water, and valveless connections between the pressure chamber and an independent source of compressed air at one end, and with the water at the other end, whereby the [illegible] level of the water in the well and the pressure of the air from the tank will always operate [illegible] the pressure chamber, causing the [illegible] the lower end of the delivery pipe, [illegible] and water [illegible] thereto in alternation.



Saunders Patent, Number 597,023.

Plate 6.

During the [illegible] of four years several water lifting pumps [illegible] by air pressure and automatically regulated have [illegible].

Patent number 588,825 was granted to [illegible] of [illegible], [illegible] on [illegible], 18[illegible] for a "Pneumatic Water Elevator". The [illegible] made for this was as follows: [illegible] in combination with an air-pump, a pipe connected with said pump [illegible] communicating with the interior of the water [illegible] near the lower end thereof, and a valve for regulating the [illegible] of air from the air pipe, of the tank or receptacle for [illegible] with the water pipe and having an outlet or dis- [illegible] spout for the water, a perforated plate or diaphragm ar- [illegible] across the interior of the tank at one side of the discharge- spout thereof, and a pipe connecting the portion of the tank, [illegible] said plate with the air pump, substantially as set forth.

[illegible] of [illegible], [illegible] was granted a patent, [illegible] [illegible]1,029 on October 5th, 18[illegible] for a "Compressed Air Water [illegible]er". This apparatus consisted of an air-tight vessel hav- [illegible] inlet and outlets for the liquid, a means for raising and [illegible]ing the vessel in the liquid and a means for closing the in- [illegible] point reached. This secures the liquid and air [illegible] vessel at the surrounding pressure. Under the force of [illegible] air the liquid is released, as the vessel is raised, [illegible] into the discharge pipe.

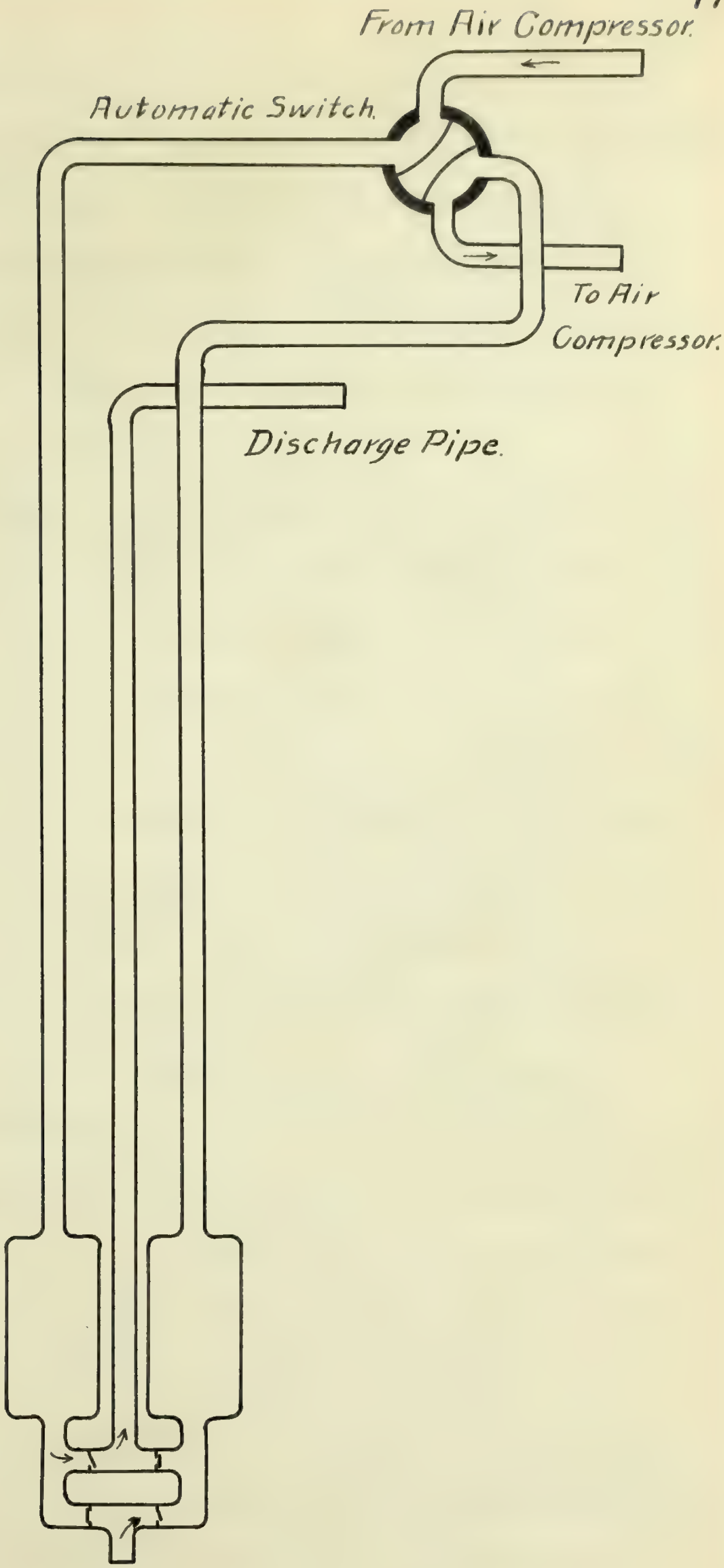
[illegible] Titus was granted Reissue- 11,[illegible] in July 18[illegible] [illegible] "Apparatus for Using Compressed Air to Elevate Water". [illegible] apparatus consists of the combination of a water-eduction [illegible] compressed-air supply pipe provided with a lateral

[illegible] at several different points throughout its height, [illegible] air may be injected into the eduction tube at different depths, also a series of cut-offs or valves adapted to open and close the valves at one or more of the different points and a means for operating the cut offs or valves.

Professor [illegible] G. Harris, who has been mentioned for his work in connection with the air lift, was granted a patent, number [illegible]37, on April 13th, 1897 for a pump. Claim number four of the application as is granted reads as follows: "A pump, consisting of two vessels each having at its bottom a pipe connection for admitting and discharging water, and each having at its top a pipe connection for admitting and discharging air; a switch connecting the air-pipes of said vessel with the other pipes leading to the inlet and discharge, respectively, of an air-compressor, said switch being adapted to reverse the connections of said air-pipes with said pipes leading to the inlet and discharge of an air-compressor, and an engine for automatically operating said switch through the medium of atmospheric pressure in conjunction with a partial vacuum created in the intake pipe of the compressor, said engine, comprising a cylinder, piston and piston-rod, a valve arrangement to admit free air to propel the piston and to allow the operating air to escape into the intake pipe of the compressor, said valve being operated by a rod connected at one end to the said [illegible] actuate the valve; and an adjustable weight mounted between the vertical guides above said piston-rod and connected thereto by a link which in its extreme positions is inclined so that said weight [illegible]

automatically as described".

Plate [illegible] while it does not give a drawing of the actual working parts of the pump, serves to show the relative position of the different parts. Professor Harris refers to the pump as a compound direct-air-pressure pump, because the liquid first flows into closed receptacles and is then driven out and raised by the admission of compressed-air. The pump has no floats or air-valves outside of the engine room and no air is allowed to escape as the exhaust from the tanks returns to the compressor, and its expanding reduces the power required to run the plant. The important feature is the automatic switch which turns the air from the emptied tank to the other, and at the same time turns the exhaust air back to the compressor. The switch can be operated by means of the partial vacuum, in the inlet pipe to the compressor, produced, when the water in either tank is drawn above its normal level, or by an electric mechanism operated by a pressure gauge on the inlet to the compressor, or a float in one of the tanks or a mechanism which will throw the switch after a fixed number of strokes of the piston. The designer computed the loss of power in the working of the pump to be 15.4 per cent. This includes the loss due to friction in both air and water pipes, and to the drop in pressure after the switching, but not including the loss in the compressor. The basis, on which this estimate was made, was on a pump to raise 1000 gallons per minute through a vertical height of [illegible] feet, the length of both air pipes and of the water pipe being [illegible] feet.



Harris Displacenent Pump.

Plate 7.

Mr. [illegible] Merrill of Plainfield, N.J. is the inventor of a form of displacement pump. In his pump the air valve has [illegible] located within the pump chamber, [illegible] either within or outside of the pump chamber. The use of floats is objectionable on account of their weight, the injury that is caused by the action of sand or gritty water, and the [illegible] of the moving parts.

On January 30th, 1908 Mr. Merrill was granted a patent, number [illegible], for an automatic air valve to be used on these displacement pumps. The valve is entirely self contained. It consists of a main air valve controlled by an auxiliary valve, both of which are operated by a differential piston, on which the air pressure is applied. By this means the valve action is prevented from hanging in an intermediate position. The movement of the air valve is predetermined and adjusted to the maximum filling capacity of the water chamber, which is so proportioned as to exceed the discharge capacity, thereby insuring complete filling of the chamber.

Figure 1, plate 8 is a sectional view through the chamber of a single acting pump of the improved type, showing the admission and discharge valves, and the absence of all other moving parts below the water level. Figure 2 on the same plate is an external view of the pump.

The automatic air valve may be placed just above the water level or any distance away from the water chamber. It is preferable however, to place the air valve near the water level, to avoid the waste of air required to fill the connecting air pipes above. When [illegible] the velocity of influx

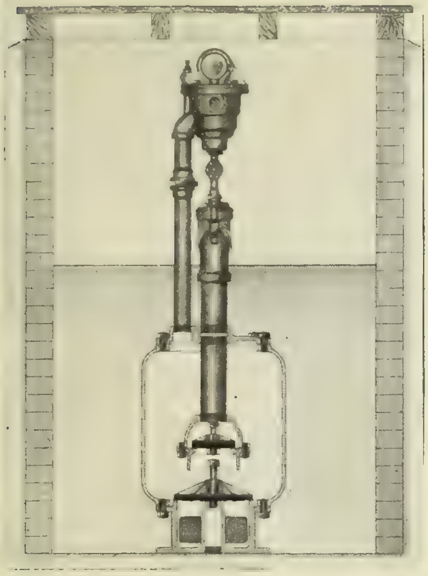


Figure 1.

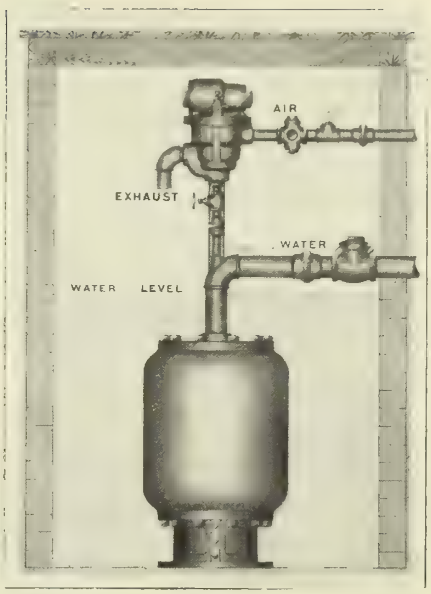


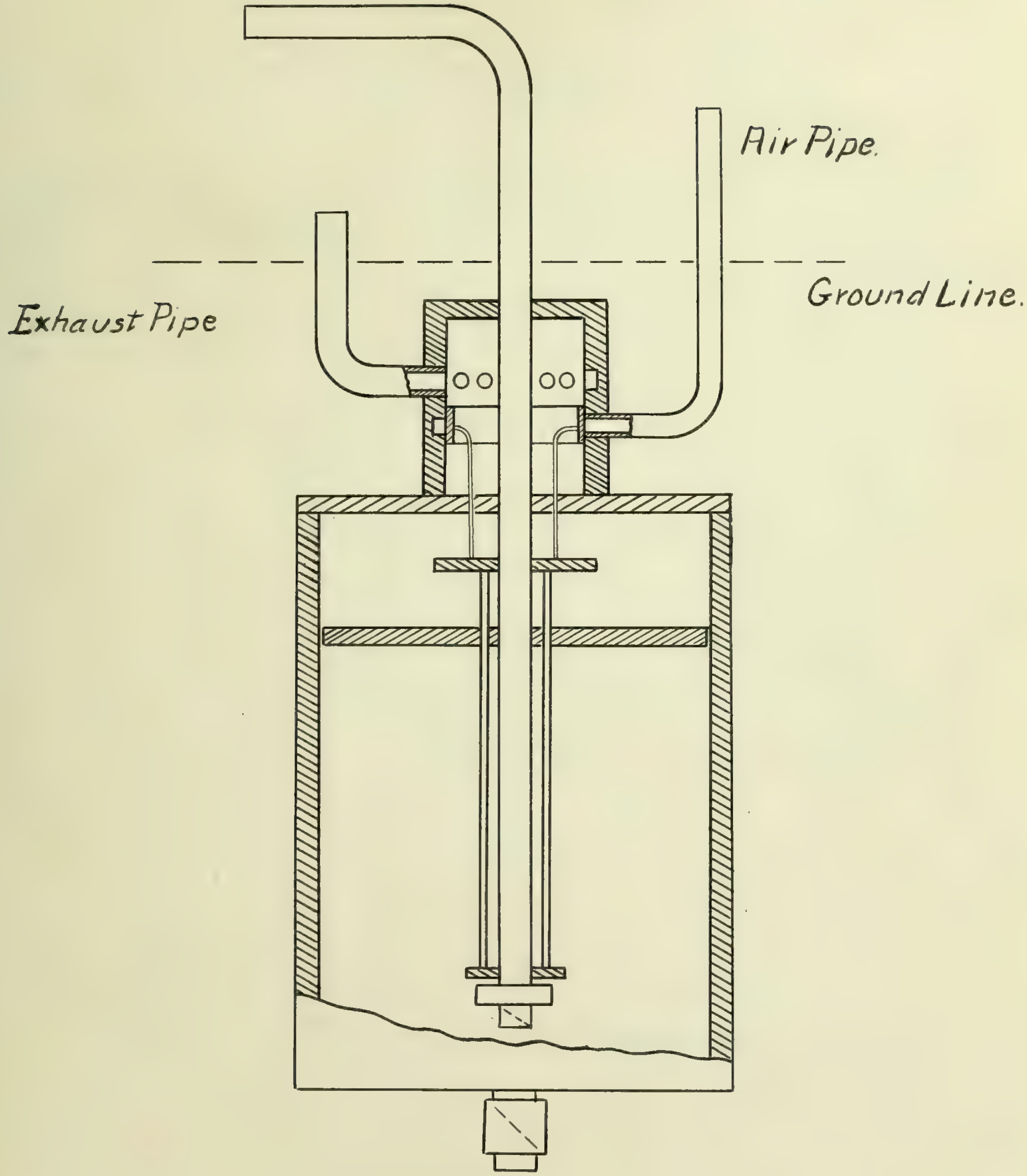
Figure 2.

Merrill Single Acting Displacement Pump.

Plate 8.

[illegible] the water in the air pipe some distance above the [illegible]ter level, and to a still greater height by an increased sub-merg[illegible]ence, which usually is sufficient to reduce the clearance loss [illegible].

[illegible] of recent date is the patent number [illegible] granted [illegible] to Mr. [illegible] Elliot of [illegible], California for [illegible] for "Raising Liquids". Plate 8 and the following [illegible] made by the patentee in his application fully describe the [illegible] the pump,- "An apparatus for raising liquids, comprising [illegible] vessel having an inlet and an outlet for the liquid to be [illegible] provided at the top with an air-inlet and air-outlet, [illegible] valve arranged to alternately close the air-inlet [illegible]tlet, a liquid-outlet pipe arranged centrally or [illegible] with respect to said valve and passing there through, rods [illegible] downwardly from the valves and provided with collars [illegible] on the liquid-outlet pipe, and a float movable on [illegible] collars."



Elliot Displacement Pump.

Plate 9.

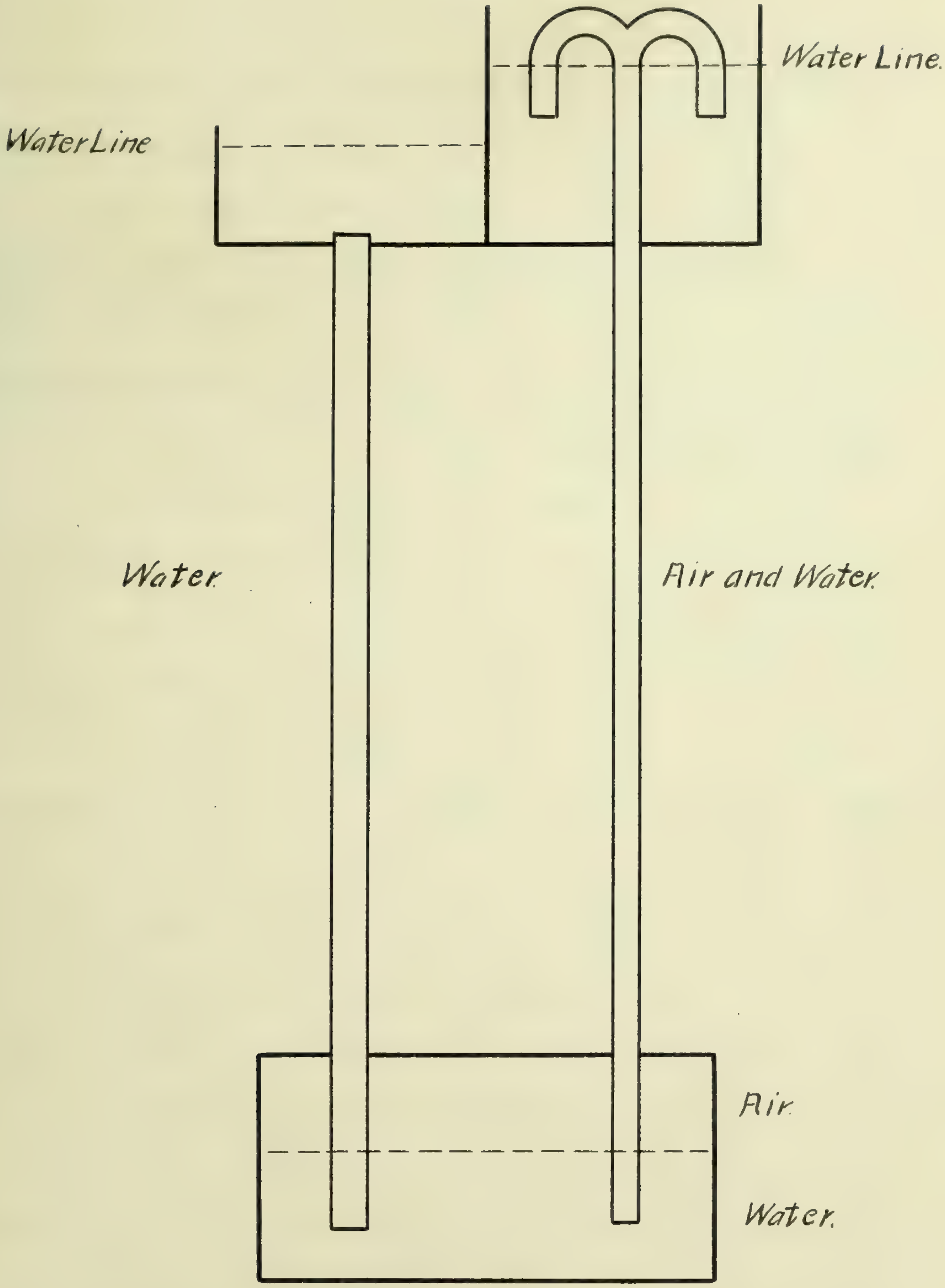
Tests of Compressing Air by Falling Water and Raising Water by Compressed Air.

Air Compression by Falling Water.

Air compression by the [illegible] of water was first attempted by Mr. Joseph P. Frizell about 1870. To accomplish this [illegible] of air and water was caused to pass down a vertical passage. At the foot of the fall the direction was changed to horizontal, then to the vertical again and carried to such a height as would give the required compression. Placed between the vertical passages and on the upper side of the horizontal conduit was [illegible], in which the air was collected, as it escaped from the water. Mr. Frizell's first apparatus for [illegible] this was rather crude. For vertical passages tubes 1-1/4 inches in diameter were used. The difference in level between the upper openings of the two tubes was about 15 inches and the height of the column was between 8 and 9 feet. The efficiency of the apparatus was estimated to be between 5 and [illegible] per cent. A larger apparatus was constructed by Mr. Frizell and after being exhibited in Boston, [illegible], was tested at the hydraulic laboratory of the Massachusetts Institute of Technology. Plate 10 shows the arrangement of the apparatus. [illegible]

[illegible]

[illegible] obtained permission, from the government officials [illegible] from the company owning the [illegible]



Frizell Method of Air Compressing by Means of a Vertical Column of Water.

Plate 10.

[illegible] shaft, for making some experiments, on a large scale, [illegible]. This shaft was sunk at the dam at St. [illegible] were being made there and had [illegible]. It was [illegible] feet deep and drained by a pipe opening into [illegible]. [illegible] of the timbering were [illegible]. A [illegible] wooden tank was constructed at the bottom [illegible]. [illegible] shafts or channels of wood [illegible]. [illegible] water, in which a considerable [illegible] required was 15 inches [illegible]. [illegible] was to return the water [illegible] passage [illegible] to pass freely from the [illegible].

[illegible] to introduce air into the water [illegible] its entrance into the vertical passage. [illegible] being nothing more than water impreg- [illegible] was made in the side of [illegible] with the [illegible]. The filling of the air chamber to this point [illegible] by the appearance of large bubbles in the ascending [illegible] by a violent [illegible]. [illegible] experiments [illegible]

[illegible] closed. At the same instant a stop watch [illegible]. [illegible] level in the receiving and discharge passages was [illegible] throughout the entire [illegible]. [illegible] surface of the discharge passage. Upon the [illegible] air bubbles here the watch was stopped. This gave the [illegible] used, its fall, the air [illegible] the time [illegible]. The capacity of the air chamber when filled to the [illegible] feet. The results of the experiments [illegible].

[illegible] efficiency [illegible] per cent is about double the best attained [illegible] previous apparatus. This efficiency would be low for a [illegible] motor, but an air compressing apparatus or a practical [illegible] exceed this model, in dimensions, in greater ratio [illegible] this exceeds the former apparatus.

[illegible] of power, or the losses of head are of three kinds. The first loss is that at entrance, or the fall required to [illegible] the air with bubbles. As near as could be estimated [illegible] one foot in all of the experiments.

[illegible] loss is the resistances to movement. In experiment [illegible] air passing, a velocity of 4.49 feet per second [illegible] shaft corresponds to a head of [illegible] feet wholly [illegible] in resistance to movement. [illegible] this the resistance to [illegible] any other velocity can be found, such [illegible] by a head which is proportioned to the square of [illegible].

[illegible] by the fact that the air does not [illegible] with the same velocity as the water. The air bub- [illegible] still water at the rate of .75 feet per [illegible]

Table 1.

[illegible] Experiments in Compressing Air by causing it to [illegible] [illegible] descending Column of Water.

[illegible] made between May 30th. and June 2nd. 1890 by Mr. [illegible] ris II.

[illegible]	[illegible] in [illegible]	Pressure of Air in Feet of Water.	Quantity of Water Cubic Feet per Second.	Quantity of Air Carried into Chamber.— Cubic Feet per Minute.	Power to [illegible] One Cubic Foot of Air.— Foot Pounds.	Total Power of Air For one Minute.— Foot Pounds.	Total Power of Water for one Minute.— Foot Pounds.	Percentage of Useful Effect.	Velocity in the Descending Shaft.— Feet per Second.
	[illegible]	28.55	5.45	27.60	2590.2	[illegible]	[illegible]	[illegible]	2.02
	[illegible]	29.47	8.89	18.57	2627.4	[illegible]	119930	40.2	3.15
	[illegible]	30.08	9.45	14.47	2708.5	[illegible]	93540	42.5	[illegible]
	[illegible]	29.91	5.72	8.52	2695.	[illegible]	53297	40.2	1.99
	[illegible]	----	14.62	[illegible]	----	----	----	----	[illegible]
	[illegible]	27.63	10.34	31.46	2193.5	[illegible]	183897	40.9	[illegible]
	[illegible]	27.75	11.49	37.45	[illegible]	[illegible]	203391	[illegible]	[illegible]
	[illegible]	27.95	11.99	[illegible]	[illegible]	[illegible]	219168	[illegible]	[illegible]
	[illegible].81	[illegible]	[illegible]	[illegible]	3130.7	[illegible]	[illegible]	50.7	[illegible]
	4.87	[illegible]	10.74	[illegible]	[illegible]	[illegible]	[illegible]	47.3	[illegible]
	[illegible].94	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
	[illegible]	[illegible]	9.43	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
	[illegible]	[illegible]	6.10	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	1.95
	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	51707	[illegible]	40.4	[illegible]

[illegible] case the total head lost can be computed and compared with [illegible].

[illegible] lost at entrance -- 1.000 feet

[illegible] " in resistance to movement=.[illegible](3.0[illegible])[illegible] / ([illegible]) -------- = .445 "

[illegible] " slip=(4.07-1.445).75 / 3.0[illegible] ------------------------------ = .[illegible] "

[illegible] ------------------------------ = [illegible] "

[illegible] gives the observed and computed heads. The computed head [illegible] short of the observed head in the experiments with velocities exceeding [illegible] feet per second, since in these cases large quantities of air were carried past the [illegible] involving resistance not taken account of in the computation. In the experiments giving the best results, the agreement is quite satisfactory.

Table 8.

[illegible]ison of Losses of Head as Observed and Computed.

[illegible]	Observed Head.	Computed Head.
[illegible]	[illegible]	[illegible]
[illegible]	3.24	[illegible]
[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	2.71
[illegible]	4.83	[illegible]
[illegible]	4.70	4.32
[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	4.53
[illegible]	4.87	[illegible]
[illegible]	[illegible]	[illegible]
[illegible]	4.78	[illegible]
[illegible]	[illegible]	4.77
[illegible]	5.03	4.93
[illegible]	[illegible]	[illegible]

[illegible] of computation was then applied to a system of [illegible] size, [illegible] shaft [illegible] feet in diameter, taking the mean

[illegible] times that of the main. Ascending shaft in the main [illegible] [illegible] 150 feet. [illegible] 15 feet. Velocity in descending shaft [illegible] feet per second. The bends should be less [illegible] [illegible] precautions in design taken, to avoid loss of head, such as a [illegible] rounded entrance to the descending shaft.

[illegible] friction head is directly proportional to the square of the [illegible], directly as the distance traversed by the water, and inversely as the mean radius of the channel. The other losses [illegible] [illegible] as the square of the velocity.

This gives in the proposed system the following losses:

[illegible] head [illegible] $\left\{\frac{6}{(4.49}\right\} \times [illegible]$ ---------- = .[illegible] feet.

[illegible] .415 $\left\{\frac{[illegible]}{(4.49)}\right\}$ ---------- = .741 "

[illegible] in reducing the water to [illegible] ---------- = 1.000 feet

[illegible] (15-1.979) $\frac{.75}{60}$ ---------- = [illegible] feet

Total losses, ---------- 3.607 feet.

Efficiency = $\frac{[illegible]}{15}$ = 76 %.

Similarly for a head, corresponding to a pressure of 100 pounds the efficiency would be 81 %.

[illegible] above experiments and computations tend to show that when [illegible] on a large scale an efficient compressor would be found.

Tests of the Air Lift in Germany.

[illegible] of October [illegible], and 15th, [illegible] published the translation of a paper by Professor [illegible] given in the "Zeitschrift" of the German society of [illegible].

Two sets of tests of the air lift were made. The first were laboratory tests, the object being to find the efficiency of the lift under given conditions; the other tests were made under ordinary working conditions in commercial plants.

[illegible] laboratory comparative tests were made using smooth and corrugated discharge pipes. The corrugations ran clear around the pipe, so that its cross section was everywhere circular, although of variable diameter. The claim was made for this pipe that its peculiar form enabled a greater amount of water to be raised, than was possible, with a smooth pipe, because the corrugations would [illegible] the drops of water from slipping back during the general upward movement of the air and water. The well used was [illegible].1 inches in diameter and 98.4 feet deep. In this were placed the air and water pipes and a rod for determining the level of the water during the test. Above the well was built a frame [illegible] feet high, on which was placed a tank. From this tank a connection was made to a measuring tank. The two pipes were hung on a tackle, so that the amount of submergence and free lift could be altered. The arrangements made it possible to measure the discharge, the free lift and the submergence. The length of the air line from the receiver to the lift was about 150 feet. As there were [illegible] a manometer was attached to the line just

before it entered the well in order to enable the air pressure to be determined.

The comparative tests first undertaken were carried out (1) with a lift having a discharge pipe 119.75 feet long and corrugations of [illegible] and 3.01 inches in minimum and maximum diameter, (2) with a lift having a smooth discharge pipe 2.76 inches in diameter, and (3) with a lift having a smooth discharge pipe of the same length and [illegible].07 inches diameter.

Three sets of tests were made with the three lifts which differed in the ratio of the height of the lift to the depth of submergence. Three separate experiments were made in each set, which differed only in the amount of air furnished, the ratio of lift to submergence being kept constant. The amount of air furnished was computed from the number of strokes of the air piston, and cards taken from the air cylinder, which gave the volumetric efficiency. The results of the tests are given in Table 4. As expected the tests showed that the corrugated pipe was a hindrance rather than an advantage. It is evident that the corrugated pipe must offer a greater resistance to the rising mixture of water and air than the smooth pipe, because with the latter the greatest efficiency between the indicated work in the compressor and the work shown by the water raised was 45 per cent, while the corrugated pipe under similar conditions gave but [illegible] per cent. The nozzles used in the two cases were different. With the smooth discharge pipe the nozzle was of brass, the form being such that the air was discharged around the entire circumference of the [illegible], while in the other case the air was introduced into the discharge pipe by a simple U bend at the bottom of the air pipe, with [illegible] end in the center of the riser. In order to determine

Comparison of Air Lifts doing [illegible]

[illegible]

Number of Test	[illegible]	Lift Feet	Submergence Feet	[illegible] per Minute	Free air Cubic Feet per Minute	[illegible] in Air Cylinder	Efficiency
[illegible]	[illegible]	51.56	63.80	57.1	19.1	1.64	44.5
	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	34.7
	[illegible]	51.57	[illegible]	90.5	45.5	4.34	27.9
	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	39.7
	[illegible]	45.57	[illegible]	[illegible]	[illegible]	3.24	34.1
	[illegible]	47.15	[illegible]	105.7	45.2	[illegible]	30.7
	[illegible]	49.57	[illegible]	[illegible]	19.0	1.71	[illegible]
	[illegible]	[illegible]	[illegible]	20.1	[illegible]	[illegible]	14.9
	[illegible]	[illegible]	[illegible]	[illegible]	40.4	[illegible]	[illegible]
	[illegible]	[illegible]	[illegible]	[illegible]	26.1	1.75	[illegible]
	[illegible]	[illegible]	[illegible]	[illegible]	36.0	3.33	32.9
	[illegible]	[illegible]	[illegible]	[illegible]	44.5	4.30	[illegible]
	[illegible]	41.59	75.24	[illegible]	[illegible]	1.62	[illegible]
	[illegible]	[illegible]	71.67	[illegible]	[illegible]	2.14	[illegible]
	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	4.40	[illegible]
	[illegible]	[illegible]	61.05	[illegible]	[illegible]	1.67	[illegible]
	[illegible]	[illegible]	60.90	[illegible]	[illegible]	[illegible]	[illegible]
	[illegible]	[illegible]	59.55	[illegible]	[illegible]	4.16	27.2
[illegible]	[illegible]	[illegible]	60.47	[illegible]	[illegible]	2.91	[illegible]
	[illegible]	[illegible]	60.34	[illegible]	[illegible]	3.95	31.1
[illegible]	[illegible]	[illegible]	61.25	[illegible]	[illegible]	[illegible]	[illegible]
	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	14.6
	[illegible]	[illegible]	[illegible]	[illegible]	45.6	[illegible]	[illegible]

[illegible] the ratio of submergence [illegible] was 4 : 5, in the next two it was [illegible] and in the last three it was 1:1. The efficiency is calculated from the ratio of [illegible] done in the air cylinder and the lift and vol -

[illegible] water raised.

[illegible] of this different construction, as the case of smooth [illegible] pipe, the brass nozzle was put on the corrugated pipe. It was found that with large air supplies and correspondingly large discharge of water there was no difference, but that with the normal air supply the common nozzle furnished 25 per cent. more water.

After the completion of these experiments a lift was constructed with a discharge pipe 3.1 inches in diameter, a submergence of [illegible].2 feet and a free lift of 24.6 feet. The brass nozzle was used in these experiments. Table 5 gives the results obtained with this lift.

Table 5.

The Effect of Changing the Volume of Air.

Number of Test.	Discharge Gallons per Minute.	Lift F Feet.	Submergence H Feet.	Free Air Cubic Feet per Minute	Cubic Feet of Air per Gallon of Water.
24	29.06	24.61	49.21	7.6	0.26
25	79.25	"	"	18.6	0.24
[illegible]	96.43	"	"	28.2	0.29
[illegible]	[illegible]	"	"	[illegible]	[illegible]
[illegible]	112.54	"	"	44.3	[illegible].39
[illegible]	116.24	"	"	50.6	.44
[illegible]	116.24	"	"	55.8	[illegible].48
[illegible]	[illegible]	"	"	[illegible]	[illegible]
[illegible]	105.67	"	"	106.0	1.00

Following the laboratory experiments, tests were made at four [illegible] establishments. The results of these experiments are [illegible] in Table 6.

Table 6.

Tests of Air Lifts at Industrial Plants in Germany.

Number of Test	Locality	Submergence E Feet.	Lift F Feet.	Diameter of Discharge Pipe Inches	Diameter of Air Pipe Inches	Discharge Gallons per Minute	Air Cubic feet per Minute.	Receiver Pressure Pounds per Square Inch	Air Cylinder.	Efficiency %	Velocity of Water at Nozzle Feet per Second.
[illegible]	Glogau	94.88	42.91	6.30	2.99	556.37	217.6	45.6	27.1	22.3	5.7
[illegible]	"	98.88	44.91	6.30	2.99	741.79	288.5	44.3	34.6	24.3	7.8
[illegible]	"	94.88	42.91	6.30	2.99	778.78	3[illegible].9	45.3	41.9	2[illegible].1	8.0
[illegible]	"	94.88	42.91	6.30	2.99	798.35	428.0	43.8	[illegible]	14.[illegible]	8.[illegible]
[illegible]	Zwickau	[illegible]	44.9[illegible]	7.56	4.94	[illegible]075.2[illegible]	598.3	50.[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	201.84	202.10	2.01	0.98	43.95	23.8	159.3	10.4	21.6	4.6
[illegible]	[illegible]ralben	403.55	229.63	2.44	1.34	65.[illegible]4	45.3	176.[illegible]	10.1	20.0	4.3

(The following two columns should be on right of above table)

[illegible] In the [illegible] plant the ratio of submergence to lift was [illegible] : 1, in the others 2 : 2. The efficiency is the ratio between the work done in the air cylinder of the compressor and in raising [illegible]. The efficiency of the Glogau compressor ranged from [illegible] in test 33 to 85.6 in test 36.-(Probably mechanical efficiency).

A comparison of tests 11 and 37 in which the lift and submer- gence were approximately alike and only the capacities were differ- ent, being 39.7 and [illegible] gallons a minute respectively, shows that the amount of air needed to raise each gallon of water and the efficiency were in close conformity. It may be therefore as- sumed that with all capacities and all lifts between 15 and 50 feet, the volume of free air needed will be two or three times the volume of water raised.

This is also shown by tests 33 and 34. The difference in effi- ciency may be attributed to the different relative submergence. While the lifts of Zwickau and Glogau are nearly the same the depths of submergence differ by about 33 feet, and because the greater depth calls for higher air pressure and hence more work of the compressor without the corresponding increase in the dis- charge of the lift, it is at once apparent that this is the cause of the smaller efficiency at Glogau. From these tests the best ratio of submergence to lift is seen to be between 1 : 1 and [illegible]. With increasing lifts the air consumption rises and the efficiency falls.

From plotted curves of the laboratory tests it was shown, that the discharge of the apparatus at first increased to a maximum with an increase of the air supply and then fell off when still more air was furnished. It was also shown by a curve that the maximal discharge was reached when the quantity supplied to the lift was small compared with its total capacity. With a discharge of 30 or more than 100 gallons a minute the air supply [illegible] strongly by the quantity of water raised.

The best economy or the highest ratio between the work done in

[illegible] of the compressor and that required by the lift and [illegible] of discharge was 45 per cent. which [illegible] in [illegible] a small discharge. With larger quantities the effi- [illegible] sank to about [illegible] per cent. and the same thing was true in [illegible] where the free lift was increased. In [illegible] of the tests the [illegible] employed were of ordinary design.

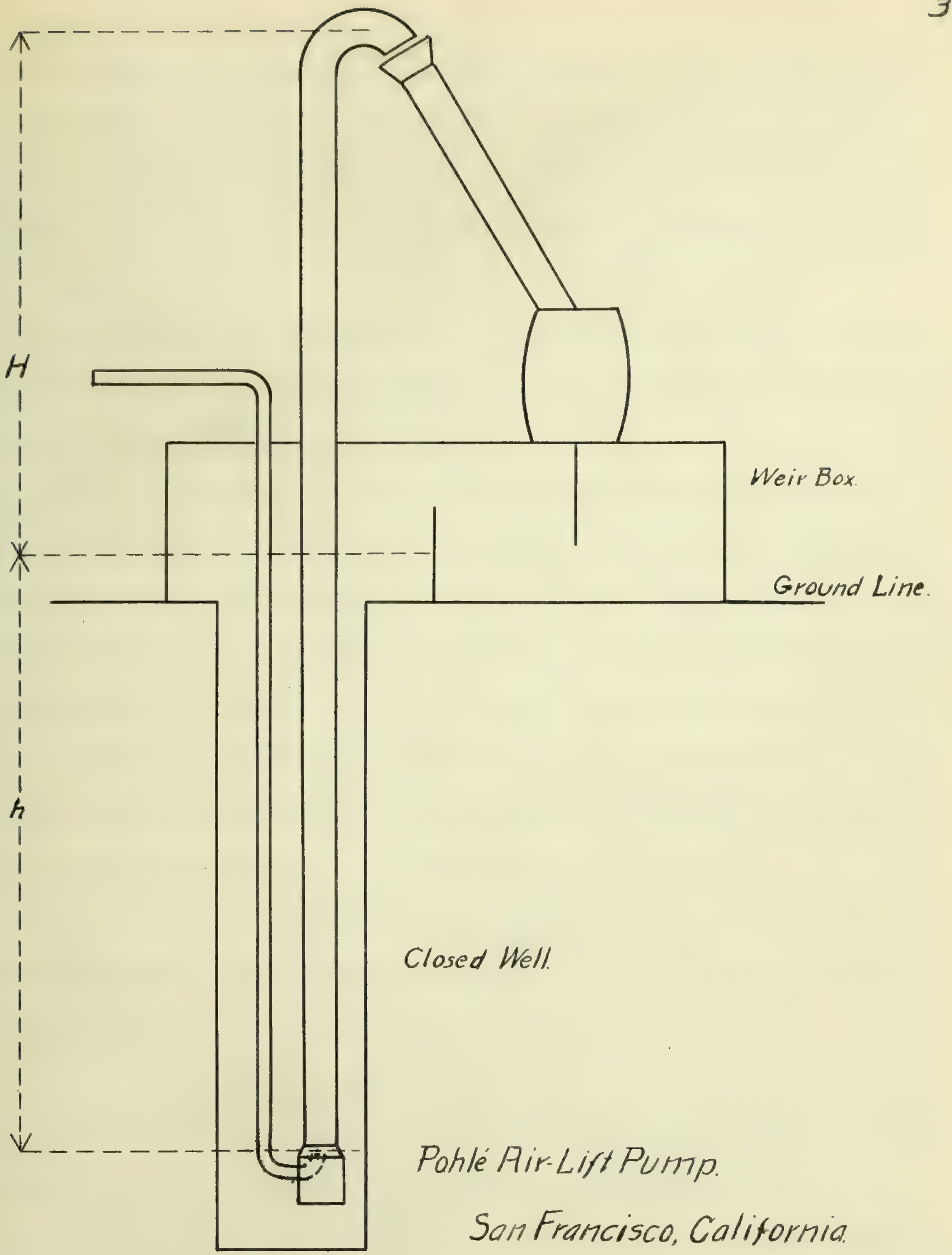
[illegible] velocities with which the water entered the discharge pipes [illegible] different plants were from 5 to 8 feet per second. [illegible] [illegible] discharge they could be kept low, [illegible] feet [illegible] [illegible].

[illegible] the air expands on its way through the discharge pipe, it [illegible] be expected that it would absorb heat from the water. This [illegible] established by the test at [illegible], where it was possible to [illegible] the temperature of the water at each end of the discharge pipe. The cooling was very slight on account of the great dif- ference between the specific heat of water and that of air. It [illegible] that the temperature of the 536 gallons [illegible] minute [illegible] [illegible] from 53.2 to 53.[illegible] degrees Fahrenheit.

[illegible] Lift in California.

[illegible] is the most extensive ever made in this country. In [illegible] an exhibit of the air lift was made at the Alameda California [illegible]. At the request of [illegible], Prof. Randall of San Fran[illegible] made a careful investigation of the theory and practical [illegible] of the pump. His reports being favorable an experimental plant was set up in San Francisco. The tests were made by Prof. Randall, who was aided by Messrs Ross E. Brown and [illegible] C. [illegible]. In [illegible] 1899 Mr. Brown read a paper before "The Technical Society of the Pacific Coast" giving the results of the tests. A little later Prof. Randall read a paper before the same society giving a mathematical discussion of the lift. On account of its length this paper was not published in the society's proceedings.

The arrangement of the apparatus used in the test is shown in plate 11. The diameter of the discharge pipe was 3 inches; of the air pipe 0.9 inches; and of the air nozzle 5/8 inches. The air [illegible] four sharp bends, and a length of 35 feet plus the depth of submersion. The water was pumped from a [illegible] pipe well ([illegible] feet deep and 10 inches in diameter) discharged into a tank and delivered over a quadrantal weir back to the well. The air pipe was so arranged that it could be raised and lowered, thus giving different ratios of lift to submersion. Due regard was not paid to the best proportion, and it is probable that the efficiency could have been increased by a few slight alterations. The air pipe should not have been reduced at the discharge end as the reduction necessitated a greater pressure in the receiver than would otherwise be required.



Pohlé Air-Lift Pump.

San Francisco, California.

Plate II.

[illegible] for computing the loss due to friction in the air pipes. The length of the pipe column, the amount of [illegible] and lift, the [illegible] in the receiver, the speed of the compressor, [illegible] the [illegible] quantities that [illegible].

[illegible] apparatus was arranged to accurately measure the quantity [illegible] delivered by the compressor to the well. Two methods, of [illegible] this supply, [illegible].

[illegible]: The cubic contents of the receiver was measured. [illegible] cocks from the receiver [illegible] and the compressor [illegible]. Beginning with the atmospheric pressure, the increase [illegible] was noted for each 30 strokes of the compressor-piston, until a pressure was reached [illegible] that required in the [illegible] tests. [illegible] mercurial column was connected with the receiver for the [illegible] of obtaining accurate measurement of pressure. The contents of the receiver [illegible] cubic feet.

[illegible] gives the results of two separate tests. The compressor [illegible] uniformly one stroke [illegible]. The atmospheric pressure [illegible] .51 feet of mercury. The air was unusually dry.

Table 7.

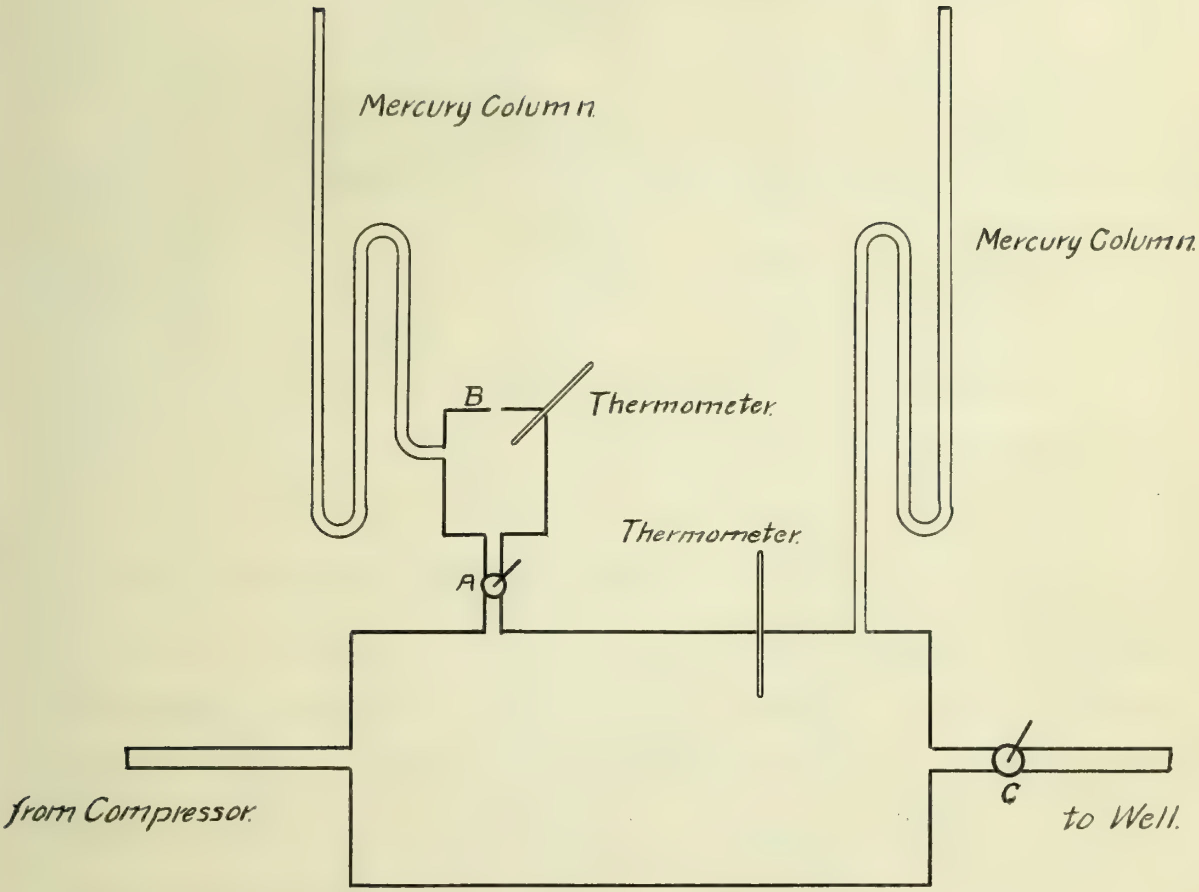
[illegible]	Temperature.				Pressure in Receiver above atmosphere. Feet of Mercury.	
	Receiver		Atmosphere			
	Test No.1.	Test No.2.	Test No.1.	Test No.2.	Test No.1.	Test No.2.
[illegible]	–	–	–		(0.73)?	0.94
[illegible]	–	–	–		1.78	1.77
[illegible]		–	–		2.45	2.56
[illegible]		–			2.84	[illegible]
[illegible]					3.95	[illegible]
[illegible]					4.67	[illegible]
[illegible]					[illegible]	5.56
[illegible]					[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	6.68	7.00

[illegible] the basis for calculating the number of pounds of air delivered, per single stroke, of the compressor, to the receiver at any required pressure. An average of the results of the [illegible] tests was adopted. Table 8 gives the values obtained.

Table 8.

[illegible] pressure [illegible]	[illegible]	5	10	15	20	25	30	35	40
Pounds of air delivered per stroke of compressor	.104	[illegible]	.093	.088	.083	.081	.079	.077	.073

Second Method. A small auxiliary chamber B, was [illegible] the receiver. See Plate [illegible]. Compressed air entering this chamber escaped into the atmosphere through a carefully calibrated circular orifice in thin plate. After a pump test had been completed, the compressor was kept running, cock C, was closed and cock A, was opened and adjusted until the conditions in the pump test, regarding number of strokes of compressor per minute and the pressure in the receiver were repeated and maintained. The pressures and temperatures of the compressed air in chamber B, and of the atmosphere, furnished the data upon which to base a calculation of the quantity of air escaping from the orifice. This quantity was evidently the same as that supplied in the pump test, and tests were made from time to time and [illegible] to check the values taken from Table 8. A few of the values [illegible] [illegible]. The diameter of the orifice was [illegible]



Apparatus for Measuring the Quantity of Air Delivered by the Compressor.

Plate 12.

[illegible] atmospheric pressure [illegible] pounds per square inch.

[illegible] of [illegible] were used.

Table 9.

[illegible] per Second computed from the [illegible]

No. of Test	[illegible] Strokes of Compressor per Minute	Pressure above Atmosphere Pounds per square inch.			Air delivered [illegible]	[illegible]
[illegible]	[illegible]	32.1	[illegible]	[illegible]	[illegible]	[illegible]
	[illegible]	30.6	[illegible]	74	[illegible]	[illegible]
[illegible]	[illegible]	34.1	[illegible]	7[illegible]	[illegible]	[illegible]

Table 10 gives a part of the results of the tests of the air lift. The efficiency of the lift is the [illegible] of the [illegible] lift [illegible] by the work "L" done in the air cylinder. The last test [illegible] a limit of lift for a given submergence beyond which [illegible] pressure is required to produce even an insignificant quantity of water. For good efficiency it is necessary that the lift should not be very great as compared with the submergence. [illegible] of the table shows, 1st. That, for a given submergence "h" and lift "H" the best efficiency was obtained when the pressure in the receiver did not greatly exceed the pressure due to the submersion. This was true only when $\frac{H}{h}$ was kept within [illegible] limits, i.e. when H was not much greater than h. [illegible] The smaller the ratio $\frac{H}{h}$ the better the efficiency, [illegible] [illegible] the best adapted pressures in the receiver, the [illegible] as [illegible] showed the following [illegible]:

For $\frac{H}{h}$ = 0.[illegible] ---------------- 50%

" " = 1.0 ---------------- [illegible]

" " = 1.[illegible] ---------------- [illegible]

" " = 2.0 ---------------- [illegible]

[illegible] 15 shows a method of piping that has been used where the [illegible] lift [illegible] as compared with the possible depth of submergence. The system consists in using [illegible] instead of having one lift cover the entire distance.

Table 10.

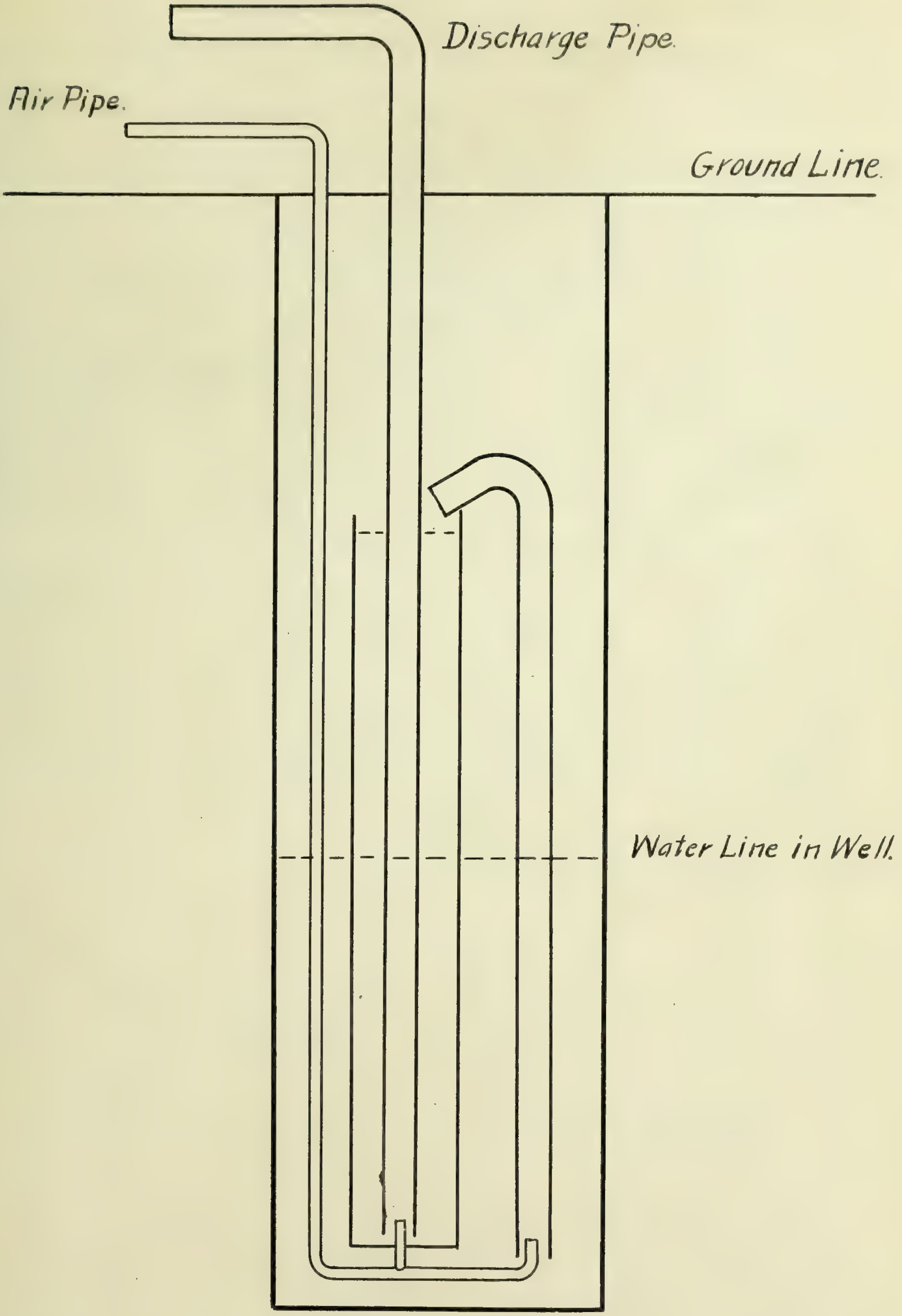
Results of Laboratory Tests of the [illegible] Air Lift [illegible]

San Francisco, California.

[illegible]	Effective [illegible] pressure, pounds per square inch.	Lift "H" in feet.	Submergence "h" in feet	Pressure corresponding to "h" in pounds per square inch.	[illegible] of air [illegible], cubic feet per second.	Water pumped, cubic feet per second.	Ratio H/h	Efficiency per cent.
[illegible]	[illegible]	75.[illegible]	53.[illegible]	23.[illegible]	.07[illegible]	.1[illegible]6	1.4	34
[illegible]	[illegible]	[illegible]	5[illegible].9	2[illegible]	.[illegible]5[illegible]	.149	1.4	4[illegible]
[illegible]	[illegible]	[illegible]	52.9	2[illegible]	.[illegible]41	.[illegible]	1.4	31
[illegible]	[illegible]	[illegible].1	5[illegible].9	2[illegible].1	.[illegible]7	.[illegible]	0.[illegible]	28
[illegible]	[illegible]	[illegible]	[illegible]	23.1	[illegible]	.[illegible]	[illegible]	46
[illegible]	[illegible]	[illegible]	53.3	23.1	[illegible]	.[illegible]94	[illegible]	5[illegible]
[illegible]	[illegible]	[illegible]	33.3	14.6	.[illegible]3[illegible]	.154	[illegible]	24
[illegible]	[illegible]	[illegible]	33.8	14.6	[illegible]	.[illegible]78	[illegible]	29
[illegible]	[illegible]	[illegible]	[illegible]	10.0	[illegible]	.0[illegible]4	[illegible]	8
[illegible]	[illegible]	[illegible]	13.7	1[illegible]	[illegible]	.007	[illegible].8	3
[illegible]	[illegible]	[illegible]	25.9	[illegible].4	[illegible]	.093	[illegible].4	13
[illegible]	[illegible]	[illegible]	[illegible]	11.2	[illegible]	.019	[illegible].4	15
[illegible]	[illegible]	[illegible].5	[illegible]	8.7	[illegible]	.149	[illegible]	1[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	8.8	.0[illegible]	.063	[illegible]	29
[illegible]	[illegible]	[illegible]	3[illegible]	11.0	.0[illegible]	.230	[illegible]	19
[illegible]	[illegible]	[illegible]	[illegible]	11.0	.0[illegible]	.144	[illegible]	4[illegible]
[illegible]	[illegible]	[illegible]	31.6	[illegible]	.0[illegible]	.295	0.7	13
[illegible]	[illegible]	[illegible]	31.3	[illegible]	[illegible]	.20[illegible]	0.7	4[illegible]
[illegible]	[illegible]	16.3	3[illegible].3	[illegible].7	[illegible]	.3[illegible]4	0.4	1[illegible]
[illegible]	[illegible]	1[illegible].3	3[illegible].3	1[illegible]	[illegible]	.2[illegible]	0.4	4[illegible]
[illegible]	[illegible]	[illegible]	15.[illegible]	[illegible]	.[illegible]6	.0[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	73.	1[illegible].3	[illegible]	.0[illegible]	.00[illegible]	[illegible].3	[illegible]
[illegible]	[illegible]	41.	10.6	4.[illegible]	.0[illegible]	.015	3.9	[illegible]
[illegible]	[illegible]	41.	10.6	4.[illegible]	.0[illegible]	.000	3.9	[illegible]

Summary

Although the tests in air compressing by the use of falling water [illegible] not exactly in line with this article, they are given.



Method of Using More Than One Lift in Deep Wells.

Plate 13.

[illegible], that a relation exists between the efficiencies in the use of compressed air to pump water, and in the reverse case, that of compressing air by water. In both cases it is shown that the efficiency is greatest when the work is done on a large scale. It was calculated by Mr. Brown after their tests in California that with a lift [illegible] greater than those of the experimental lift, an efficiency of over [illegible] could be obtained. A conclusion, quite similar, was reached by Mr. Frizell from computations obtained after his tests on air compressors had been made at St. Anthony Falls, Minnesota.

Both the California and the German experiments show that the efficiency is greatest when the ratio of lift to depth of submergence is about 1 : 1. They also show that the air pressure should about equal the pressure due to the height lifted, and that too great a volume of air delivered decreases the efficiency.

[illegible] the Air Lift at [illegible].

Water Works at [illegible], Illinois, 1897.

The supply is derived from three artesian wells, [illegible] inches in diameter, and from 1050 to 1300 feet deep. Two of the wells [illegible] a reservoir of 500,000 gallons capacity. When the reservoir is empty these two wells flow at the rate of [illegible] gallons [illegible], but when it is full and the well tubing submerged the flow drops to 100 gallons per minute.

The amount of water was not sufficient during the summer months, [illegible] air lift system was established.

[illegible] the two wells flowing into the reservoir, they were able to secure 1081 gallons of water per minute, by the lift, with the reservoir empty; and 1010 gallons per minute with the reservoir full and the well tubing submerged. This increase is equivalent to almost ten times the ordinary flow of [illegible] under the latter conditions.

An Ingersoll Sergeant Drill Co. Class "H" air compressor, having [illegible] cylinder 14 inches in diameter, and air cylinder 10-1/4 inches in diameter, with a 12 [illegible]. The speed [illegible] revolutions per minute. (Engineering Record, May 22nd, 1897).

[illegible] R.R., [illegible].

[illegible]

[illegible] Pohlé air lift which had been [illegible] [illegible] with a 12 [illegible] steam cylinder, a 14 inch air cylinder [illegible] inch stroke [illegible]. The well has a [illegible] inch casing [illegible] feet long. Inside of

[illegible] pipe through a 5-1/2 inch [illegible], the [illegible] [illegible] reduced to 3-3/4 inches, and a short [illegible] [illegible] [illegible] the water at a height [illegible] [illegible] the center of the discharge pipe. Indicator [illegible] [illegible] steam cylinder.

[illegible] results were obtained:

[illegible] from surface of water to center of discharge pipe -- 133 feet.

[illegible] lift including friction (about) ---------------- 145 feet.

[illegible] from surface of water to nozzle ---------------- 128 [illegible].

[illegible] pressure above atmosphere ---------------- 55 pounds.

[illegible] pressure at nozzle ---------------- 55.3 pounds.

[illegible] pressure steam cylinder, head end, ------ 41.8 pounds.

[illegible] pressure steam cylinder, crank end, ---- 45.5 pounds.

[illegible], head end ---------------------------- 110 sq. inches.

[illegible] piston, crank end ---------------------------- [illegible] sq. inches.

[illegible]

[illegible]

[illegible] per minute (gallons) ---------------- 207.

[illegible] (water-horse power) ---------------- 7.47.

[illegible] ---------------------------- 1[illegible].47 %.

[illegible] amount of air used ---------------- 55.8 pounds.

[illegible] efficiency is partly due to the three following causes: (1) [illegible] apparatus was too large for the amount of water to be obtained from the well, without lowering the water in the well. (2) [illegible] of the inside of the [illegible] [illegible].

[illegible] design of the nozzle of the air pipe. ([illegible] July 12 '9[illegible])

[illegible] Air Lift at [illegible], [illegible].

[illegible] an interesting history [illegible] of the air lift at [illegible], Illinois, and the final adoption of deep well pumps. In 18[illegible] the city [illegible] was in need of a greater supply of water. [illegible] four eight [illegible] wells were [illegible] [illegible] well pump was placed in each well. [illegible] gallons of water per minute were obtained from each well. This fell short of the immediate demand for water. It was then decided to install the "Pohle Air Lift". On September [illegible], 189[illegible] [illegible]. A [illegible] compressor was used. The [illegible] dimensions and results [illegible] follows:

Diameter of discharge pipe ---- 4 inches.
[illegible] pipe submerged ---- [illegible] feet.
Diameter of air pipe ---- [illegible] inches.
Diameter of air pipe at lower end ---- 1.5 inches.
[illegible] ---- [illegible]
[illegible] (gallons per minute) ---- [illegible].
[illegible] yield (gallons per minute) ---- [illegible].

[illegible] inch discharge pipe [illegible] substituted for the four inch pipe. With a submergence of 9[illegible] feet the discharge was 5[illegible] [illegible].

Additional tests were made between September [illegible] [illegible] The air pressure varied from [illegible] to [illegible] pounds, [illegible] per minute varied from [illegible] to 1[illegible], and the per cent [illegible] varied from [illegible] to [illegible]. The discharge [illegible]

[illegible] with [illegible] pressure, and number of revolutions of the compressor. [illegible] points [illegible] did not seem to materially increase the [illegible] water:

[illegible] per minute	180	[illegible]	[illegible]
Air pressure (pounds)	40	[illegible]	[illegible]
[illegible] (gallons per minute)	516	51[illegible]	45[illegible]

[illegible] pipes [illegible] and fifty feet [illegible] materially increasing the flow except at high speeds.

[illegible] was next [illegible] the [illegible] discharge [illegible] the casing. [illegible] increase the flow to 804 gallons, with [illegible] revolutions and [illegible] air pressure; [illegible] a flow of [illegible] gallons; next [illegible] feet was [illegible] with a flow of [illegible] gallons. [illegible] feet of 1-1/4 inch [illegible] feet of 2-inch pipe was [illegible], [illegible] 150 feet [illegible]. With [illegible] the same results as before were obtained, namely [illegible] gallons per minute; with [illegible] revolutions and 40 pounds air pressure, [illegible] gallons were obtained; [illegible] feet of air pipe was next tried [illegible] best result produced was 869 gallons. The pipe was shortened to 265 feet and with [illegible] revolutions and [illegible] pounds air pressure [illegible] gallons was produced.

[illegible] that the company selling the "[illegible] Air Lift [illegible]", [illegible] contract with the city to put in a plant, guaranteeing [illegible] gallons [illegible] from the four [illegible] wells, [illegible] head [illegible] feet below the surface of the ground, the [illegible] being six feet below the surface. The final test was [illegible] The test showed about 1,500,000 gal-

[illegible]

[illegible] of 1895 [illegible] pipe [illegible] about [illegible] 18 inches long [illegible] 19 [illegible]. It [illegible] decided that air was wasting through [illegible] without producing any effect. [illegible] was put in each well to a depth of [illegible] feet, and the [illegible] 1-1/2 inches in diameter [illegible] feet. The air discharge [illegible] was 5/8 inches in diameter at the end [illegible]. [illegible] wells were pumped without trouble, and about 1,[illegible],000 [illegible] to the required height.

[illegible] that the [illegible] need not be the same in all [illegible] feet [illegible] 73 feet in the second, 88 feet in the third and [illegible] feet in [illegible].

[illegible] cost of pumping was about $10.00 per million gallons. [illegible] the air lift [illegible] increased to $11.5[illegible] per [illegible] gallons. In 1896 the pumping plant was again [illegible] of maximum consumption. In January [illegible]7 it was determined to sink a 100 foot shaft, at the bottom of which were to be located three pumps driven by [illegible] at the surface. Tunnels [illegible] the shaft to [illegible] wells as were necessary, and the pumps and wells connected [illegible] running through the tunnels. The plant is expected to [illegible] 7,000,[illegible] gallons per 24 hours. A [illegible] test of the plant [illegible] made gave 58,000,000 foot pounds of work done per [illegible] of dry steam.

[illegible] lift has probably been given as thorough a test at this [illegible] place in this part [illegible]. The failure of

[illegible] at this place, as due to its inability to supply the [illegible] at the same time the cost of pump- ing [illegible] air lift was greater than [illegible] wells [illegible] in use. The result is that air lift has been entirely [illegible] (Illinois Society of Engineers and [illegible] 1899 and Engineering Record, March 18th. 1899).

[illegible] Air Lift of the Champaign and Urbana Water Company, at Urbana, Illinois.

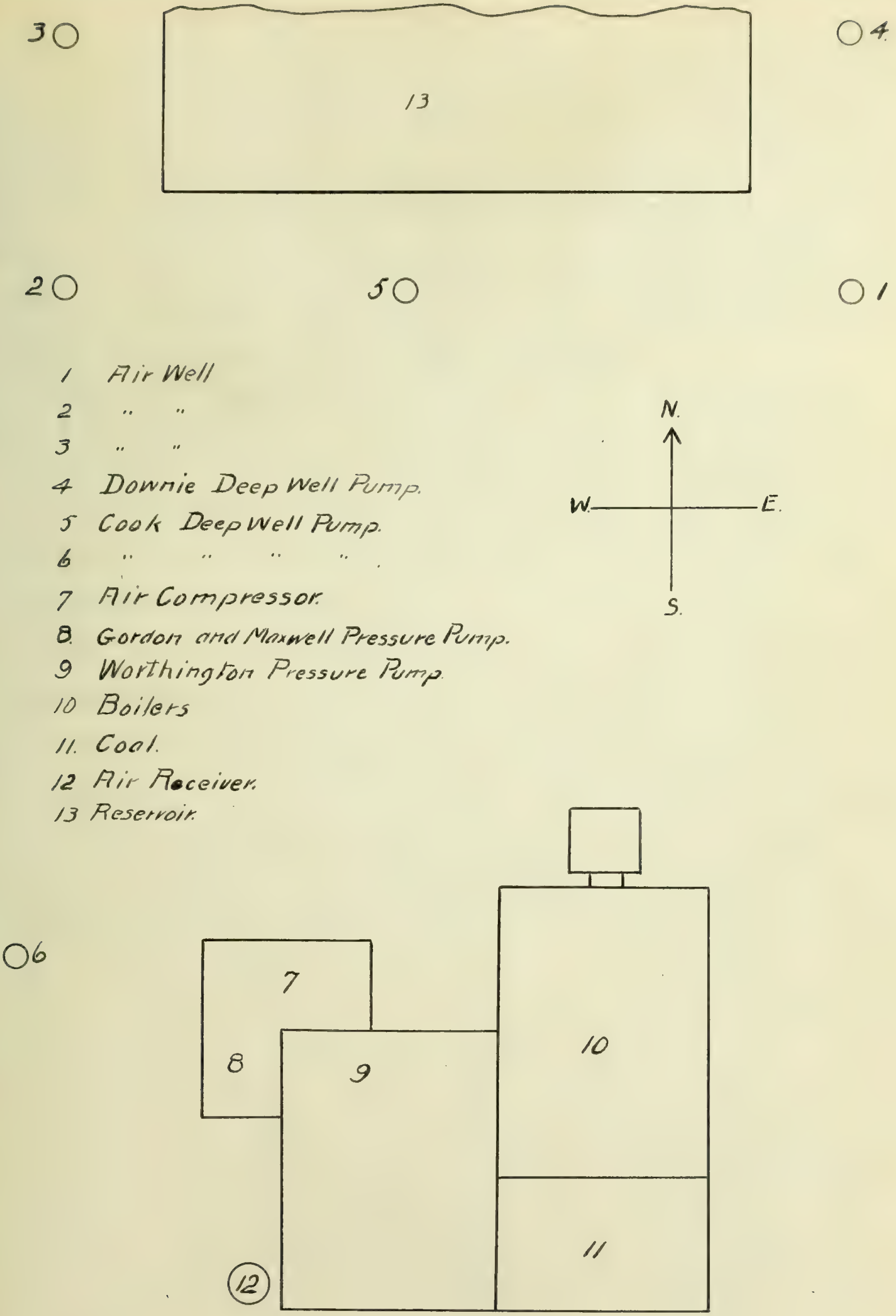
[illegible]

When the subject of the air lift was first taken up it was expected that some laboratory tests comparing different kinds of [illegible] and different methods of piping could be made. When however the time came to make the tests, it was impossible to [illegible] a place and suitable apparatus for such work. A test of the air lift at the Champaign & Urbana Water Works Pumping station has been arranged for and made. The plant is located in the north part of Urbana on the north side of the Big Four Railway tracks. The water is raised from wells about 165 feet deep, into a reservoir of 250,[illegible] gallons capacity and from there pumped into the city mains. The average daily requirement at present is about [illegible],000 gallons of water per twenty four hours.

About two years ago the water supply was not equal to the demand, so additional wells were drilled, and four of them connected with an air compressor which was then installed. Within the last few months it has been found necessary to again increase the capacity of the plant. This time geared, electrically driven deep well pumps are to be substituted for the air lift wells, and also for part of the steam deep well pumps that are now in use.

At the time the test was made there were in operation two pressure pumps, one a "Worthington" & the other a "Gordon and Maxwell"; one "[illegible]" double acting deep well pump, two "Cook" deep well pumps and three air wells. Two "Cook" pumps had been disconnected the previous week.

Plate 14 shows the location of the air compressor, receiver, air wells and reservoir. The manner of piping at the wells is shown



Champaign and Urbana Water Company

Plate 14.

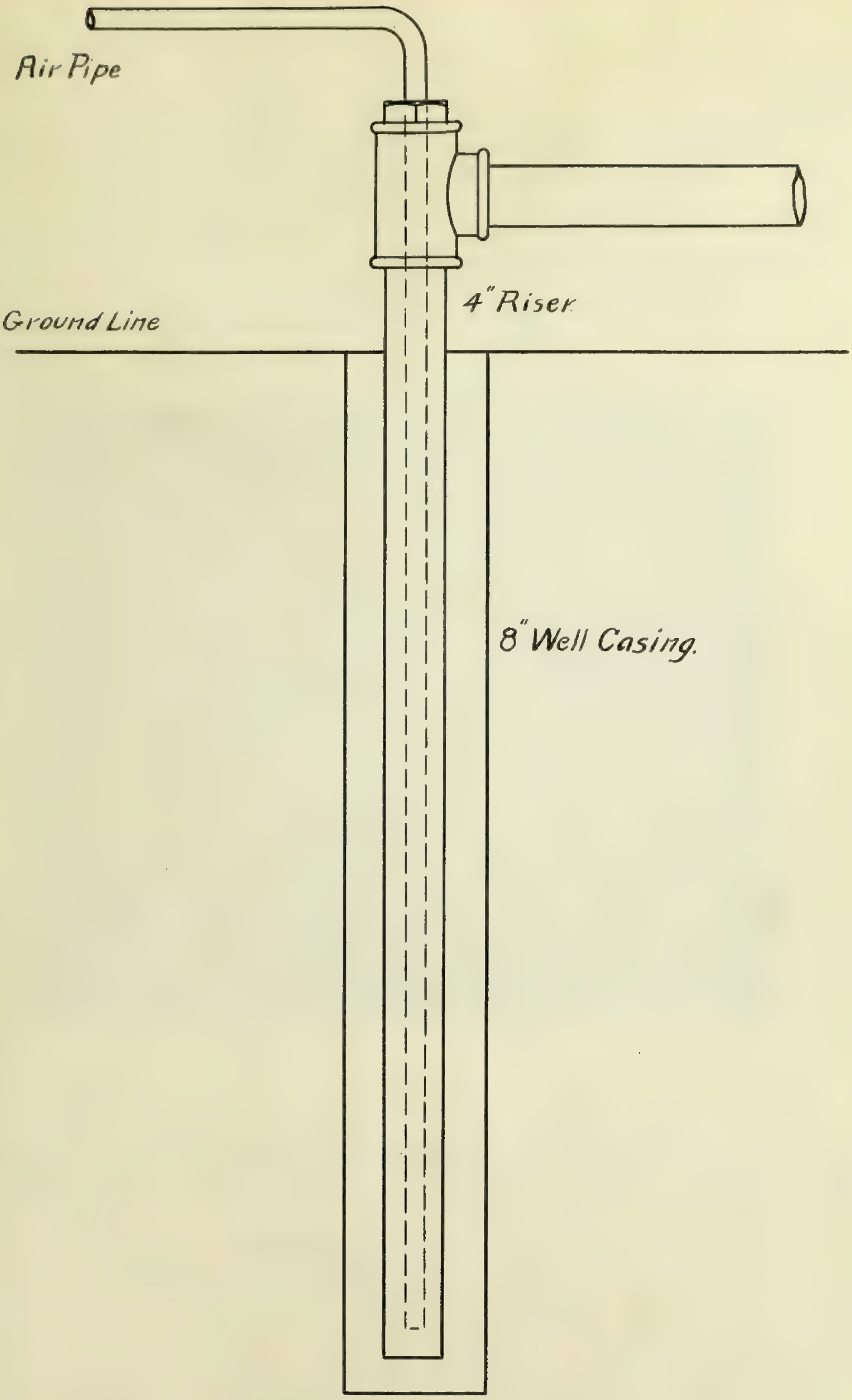
in [illegible]. All of the air wells had an 8 inch casing in which [illegible] a 4 inch vertical riser with an air pipe 1-1/2 inches in [illegible] inside of it. Well number 2, which gave the [illegible] to discharge into a Measuring Tank for [illegible]. [illegible] gives a photograph showing the measuring tank, [illegible] to it from this well. An air gauge was placed [illegible] about 10 feet from well number 2.

[illegible] tests were [illegible] this plant. Previous to the first test some readings were taken in order to learn the general [illegible] of the lift. Table 11 gives the readings and [illegible]. In all of the air well tests [illegible] in the Measuring Tank.

Table 11.

[illegible] Readings Taken at Air Well Number 2, [illegible] for Different Air Pressures and Speeds of the Compressor.

Revolutions Per Minute.	Air Pressure At Well. Pounds.	[illegible] Head [illegible] Feet.	Water Gallons Per Minute.
[illegible]	74	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	74.31
[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	71.37
[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]



Air Well Piping at the Urbana Water Works.

Plate 15.

Measuring Tank for Jet Meter, at Pumping Station.

Urbana, Illinois.

Plate 16.

[illegible]se readings agree in every way that the tests [illegible]. [illegible].

The first test was made with the air supply shut off from wells [illegible], at which the measuring [illegible] placed in use. In this test the amount of water [illegible] [illegible] different air pressures and different air volumes was found. Indicator cards were taken from both the steam and air cylinders of the compressor. In the second test all of the wells were in operation and cards taken from the compressor so that the work [illegible] when it was working under normal conditions, could be determined.

The first test was made March 31st, 1906. Additional sections of pipe had been added to the well used in order to reach the measuring [illegible]. This made the distance [illegible] had to be raised [illegible] feet and the depth of submersion about [illegible] feet. These distances were measured when the well was not in operation. It was intended to measure the depth to the water level in the well for different discharges. This was attempted but had to be given up for the reason, that the discharge pipe did not hang at a uniform distance from the well casing, and in measuring the distance to the water level the float used was caught between the pipes and [illegible] lost from the string to which it was fastened. The test consisted in running the compressor at different speeds and noting the air pressure at the well, the amount of discharge and at the same time taking indicator cards from the compressor. From this [illegible] the free air per minute, and the gallons of water per minute [illegible]. Table 17 gives the results of this test.

It was intended to find the efficiency of the lift for different volumes of air used and different discharges of water.

[illegible] efficiency in this case is the weight of water raised times the distance it is raised, divided by the work done in the air cylinders of the compressor. As the water level in the well could not be found for the different discharges that could not be done.

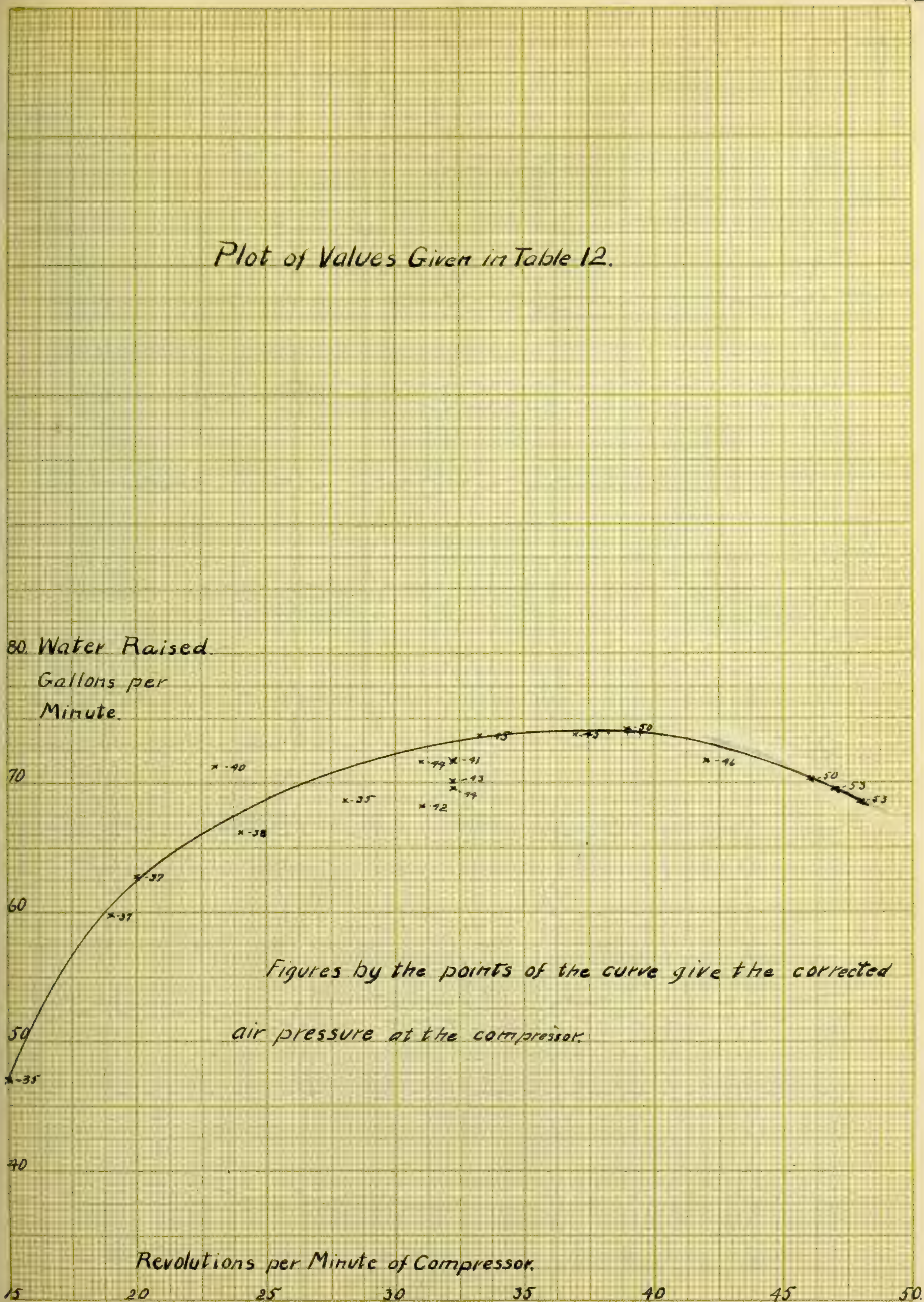
Table 19.

Water Discharged by Air Well Number 2 with different Air Pressures and [illegible].

[illegible]	Air Gauge Reading at Compressor. Pounds. *	Air Gauge Reading Well [illegible]	[illegible]	Free air per minute, Cubic Feet.	Water Raised. Gallons per Minute.
15	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

* Note.- The air gauge readings at the compressor are five pounds high. Plot of table given on page [illegible].

It is probable that the water level would fall some for a heavy discharge. At the same time it seems reasonable to consider that the largest discharge of the air wells did not lower the level [illegible]



EUGENE DIETZGEN CO., CHICAGO.

[illegible] about [illegible],000 gallons per day, [illegible] had been [illegible] time, in the air [illegible] air wells but had been replaced by a [illegible] double [illegible] discharge a- bout [illegible],000 gallons per twenty four hours. As [illegible] case the efficiency is found for [illegible]ties of discharge [illegible] lowered. These results are given in Table 17.

Table 17

[illegible] According [illegible] Distance [illegible] Water Level, in the Well, to Remain Constant.

[illegible]te.	Horse Power Developed in Air Cylinder.	Hydraulic Horse Power.	Efficiency %.
[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]

[illegible] the greatest [illegible] of the water level that [illegible] expected the ratio in no case could be hardly increased [illegible] than one third of the amount given. This shows that the [illegible]ge ratio of the work of the rising water, to that done in the air cylinder [illegible] ten per cent. This agrees in general with the results [illegible] in some of the experiments made by Professor [illegible] in [illegible]-[illegible]. That is, as the ratio of the water lift to that of the

[illegible] compression [illegible] great [illegible], the efficiency being [illegible]. Again, the amount of free air used per gallon of water is [illegible] large. This also is due partly to the increased [illegible] mentioned above. Then the compressor is altogether too large for one well, that is, gives too great a discharge of air, and [illegible] efficiency was probably decreased a great deal by this [illegible].

Test Number 2, April 3rd, [illegible].

The second test was an efficiency test of the compressor working under the normal conditions, [illegible] of the wells. The [illegible] dimensions of the compressor and the results of the test [illegible] given below.

Builders' Name: Stilwell - Pierce & Smith-

Vaile Co., Dayton, Ohio.

Diameter of steam cylinder, high pressure	[illegible] inches.
" " " " low "	[illegible] "
" " air cylinder	[illegible] "
[illegible]	[illegible] "
[illegible]	[illegible] "
" " main valve rod	[illegible] "
" " expansion valve rod	[illegible] "
[illegible]	[illegible] "
" " [illegible]	[illegible]
" " [illegible]	[illegible]
" " air [illegible]	[illegible]
[illegible]	5400 pounds.

[illegible] expansion valve is used on the steam cylinder and an [illegible] valve on the [illegible] pressure cylinder.

[illegible] The air inlet and the air outlet valves are placed in the [illegible]. The air inlet valves are of the poppet type, opened by the pressure of the outside air and closed by the pressure in the cylinder and by spiral springs.

[illegible] frame which [illegible] the valve seat. This frame is screwed into the cylinder [illegible] are five inlet valves in each cylinder head, each [illegible] a face area of 4.3 square inches. The air outlet valves are [illegible] form. They are opened by the pressure of the air in the air cylinder and closed by the pressure of the air in the receiver, assisted by spiral springs. The bottom of the cup forms the seat of the valve. These valves seat in openings [illegible] in the cast iron cylinder head. This does not allow the [illegible] be reground and when a new valve is put in it has to [illegible] itself down to its seat, as the seat cannot be removed with [illegible]. Each cylinder has [illegible] three air outlet valves, each [illegible] a face area of 2.4 square inches. The entire valve [illegible] because the valves take up so much of the cylinder [illegible] that no room is left in which to circulate [illegible].

[illegible] governor on the compressor. During the test the point of cutoff was not altered and the speed of the compressor was regulated by the steam pressure.

Indicator cards were taken every fifteen minutes, during the test. Four Tabor indicators were used, one on each cylinder.

Plate 17 gives a photograph of the air compressor. The kind of [illegible] motion used and the manner of attaching the same can be seen.

Air Compressor

at Pumping Station Urbana, Ill.

Plate 17.

Table [illegible] gives the mean effective pressures [illegible] [illegible] and [illegible] [illegible] air cylinders. The mean effective pressure is calculated from each diagram, by dividing the area of each card by the length of each card and multiplying by the scale of the [illegible] [illegible] [illegible] [illegible] 80 on the high pressure steam [illegible] [illegible] [illegible] pressure steam cylinder, and 40 on the air cylinder instruments.

[illegible] [illegible] and [illegible] give a set of t[illegible] [illegible] steam [illegible] air cylinders. There is quite a large drop in [illegible] [illegible] between the high and low pressure steam cylinders. [illegible] distribution between the high and low pressure cylinders [illegible] because the high pressure cylinder does twice as much work as the low pressure [illegible].

[illegible] [illegible] gives the Indicated Horse Power [illegible] [illegible] the air cylinders and also the ratios between the total air and steam [illegible] powers. This last result is the mechanical efficiency of the [illegible].

Total Quantities.

1. Duration of test [illegible] [illegible] hours.
2. Total revolutions of compressor ----- [illegible]
3. [illegible] feet of free air displaced ---------------- [illegible]
4. Total steam consumption, (feed water to boiler) pounds. -- [illegible]
5. Water used in jackets of air cylinder [illegible] [illegible]

Average Quantities.

6. [illegible] indicated horse power of air cylinders [illegible]
7. [illegible] [illegible] [illegible] power of steam cylinders.. [illegible]

8. [illegible] ([illegible] cylinders) / ([illegible] steam cylinders) --- [illegible]

9. [illegible] [illegible] compressor by gauge (pounds) [illegible]

TABLE 14.
Mean Effective Pressures.

Number.	R. P. M.	Air Pressure at Compressor. Pounds.	Steam Pressure. Pounds.	Steam Cylinders.				Air Cylinders.			
				High Pressure.		Low Pressure.		North		South.	
				Head.	Crank.	Head.	Crank.	Head.	Crank.	Head.	Crank.
1	31	40	70	47.95	47.00	8.52	7.28			20.36	19.88
2	32	45	70	47.95	46.85	9.79	9.04	22.64	21.72	21.28	18.96
3	64	50	85	50.00	48.00	11.04	10.78	25.60	24.76	25.20	21.04
4	65	50	85	50.50	48.80	10.92	10.87	25.40	24.16	24.52	20.76
5	66	48	82	49.70	47.35	10.40	10.40	25.44	24.16	24.80	23.20
6	66	50	84	50.50	46.90	10.60	10.00	25.48	24.20	26.00	23.44
7	62	50	83	51.90	49.65	10.40	9.80	24.96	23.60	24.12	20.28
8	46	45	77	50.00	48.45	9.20	8.80	24.96	23.40	23.96	20.84
9	51	45	78	50.00	48.30	9.60	9.00	25.00	23.40	24.12	21.08
10	58	48	83	50.50	48.45	10.56	10.15	24.64	24.56	24.64	24.00
11	52	45	80	50.00	48.25	10.32	9.60	25.36	24.16	23.96	21.76
12	57	48	83	50.00	48.95	10.78	9.72	26.08	24.52	25.12	23.16
13	56	48	82	49.50	49.50	9.84	9.60	25.36	24.16	24.60	21.76
14	57	48	82	49.65	47.50	10.80	9.51	25.52	24.08	24.88	23.16
15	50	45	80	49.45	48.00	10.30	9.60	24.00	22.40	24.68	21.88
16	53	46	81	48.75	48.50	10.80	9.60	25.60	22.56	24.64	21.88
17	52	45	80	49.44	47.50	11.06	10.00	25.20	24.40	24.92	21.88

Form D—2-10-98—5 M—W.

M. E. LABORATORY U. OF I.

SCALE 50 SIZE CYL 12" x 18" ENGINE TIME OR NO. 7

BOILER PRES. DATE

END

R. P. M

VAC. GAUGE

NOTE: TAKE DIAGRAM ON THIS SIDE OF PAPER

Head High Pressure. Crank.

Form D—2-4-97—5 M—W.

M. E. LABORATORY U. OF I.

SCALE 20 SIZE CYL 18" x 18" ENGINE TIME OR NO. 7

BOILER PRES. DATE

END

R. P. M.

VAC. GAUGE

NOTE: TAKE DIAGRAM ON THIS SIDE OF PAPER.

Low Pressure.

Steam Cards.

Plate 18.

Form D—2-10-98—5 M—W.

M. E. LABORATORY U. OF I.

SCALE 40

SIZE CYL. 14" x 18"

ENGINE

TIME OR NO. 7

BOILER PRES.

DATE

END

R. P. M

VAC. GAUGE

NOTE: TAKE DIAGRAM ON THIS SIDE OF PAPER

Head. North Cylinder. Crank.

Form D—2-4-97—5 M—W.

M. E. LABORATORY U. OF I.

SCALE 40

SIZE CYL. 14" x 18"

ENGINE

TIME OR NO. 7

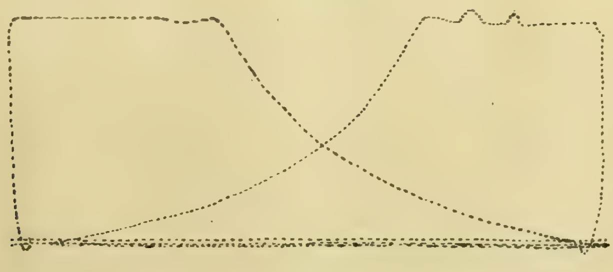
BOILER PRES.

DATE

END

R. P. M.

VAC GAUGE



NOTE: TAKE DIAGRAM ON THIS SIDE OF PAPER.

South Cylinder.

Air Cards.

Plate 19.

TABLE 15.

Horse Powers.

Number.	Steam Cylinders.				Air Cylinders.				Total		Efficiency %
	High Pressure.		Low Pressure.		North		South.		Steam	Air	
	Head	Crank	Head	Crank	Head	Crank	Head.	Crank.			
1	7.43	7.28	3.01	2.58			4.41	4.31	20.30	17.44	85.90
2	7.42	7.26	3.45	3.19	4.86	4.60	4.67	4.02	21.32	18.15	85.12
3	16.25	15.60	8.18	7.99	11.57	10.95	11.39	9.32	49.02	43.23	90.02
4	16.41	15.86	8.09	8.04	11.57	10.99	11.15	9.44	48.40	43.15	89.10
5	16.40	15.62	7.85	7.85	11.67	10.87	11.37	10.54	47.72	44.45	91.68
6	16.67	15.51	8.00	7.55	11.93	10.54	11.69	9.89	47.73	44.05	90.02
7	15.57	14.90	7.30	6.93	10.76	9.98	10.36	8.57	44.79	39.67	84.05
8	11.50	11.14	4.82	4.62	7.91	7.50	6.58	6.52	32.08	28.61	89.21
9	12.75	12.32	5.78	5.24	8.85	8.14	8.53	7.33	36.09	32.85	91.02
10	14.64	14.05	6.87	6.02	9.72	9.52	9.89	9.50	41.58	38.63	93.14
11	13.00	12.55	6.12	5.51	9.18	8.58	8.66	7.72	37.18	34.14	91.82
12	14.25	13.95	7.00	6.32	10.34	9.48	9.99	8.96	41.52	38.77	93.30
13	13.86	13.86	6.29	6.12	9.86	9.18	9.54	8.26	40.13	36.84	91.82
14	14.15	13.84	7.02	6.48	10.01	9.30	9.50	8.96	41.19	37.77	91.64
15	12.36	12.00	5.92	5.47	8.33	7.62	8.38	7.44	35.75	31.77	88.87
16	12.90	12.85	6.52	5.80	9.42	8.16	9.06	7.93	37.87	34.57	91.52
17	12.85	12.35	6.56	5.93	9.10	8.68	8.99	7.77	37.69	34.54	91.64
Average									38.84	35.21	90.63

10. Average steam pressure, by gauge (pounds) ———— [illegible]

11. Average atmospheric pressure, by barometer ———— [illegible]

12. Average revolutions per minute, by counter ———— [illegible]

13. [illegible] feet of free air displaced per pound of steam ———— [illegible]

14. Steam consumption per I.H.P. of [illegible] cylinder,

[illegible] ———— [illegible]

15. Steam consumption per I.H.P. of air cylinder,

per hour (pounds) ———— [illegible]

16. If the compression of air had taken place without any increase of temperature, the I.H.P. of the air cylinder would have been ———— [illegible]

17. Efficiency of [illegible]

[illegible] ———— [illegible]

18. [illegible] power is [illegible] useful [illegible] ————

During the test the air gauge [illegible] compressor and the receiver [illegible] between 30 and 50 pounds. From all readings of this gauge five pounds should be subtracted.

The mechanical efficiency of the compressor was higher [illegible]. At the same time this is not impossible [illegible] the compressor was slow and the bearings large [illegible]. The thermal efficiency of the air cylinder [illegible] is the ratio between the card that would be given if isothermal compression were followed and the card that is actually given. [illegible] height of the air cylinder card, if isothermal [illegible] followed, a pressure corresponding closer to

that shown by the air gauge and that shown by the air card [illegible] the end of the exhaust portion of the stroke was taken. [illegible] as a vacuum and the [illegible] pressure as given by the barometer as a datum, the area and mean height of the air card [illegible] compression was computed. From this the mean effective pressure and horse-power was computed. [illegible] mean effective pressure was computed for five cards and the average of the values [illegible] horse-power for the different [illegible]. For ordinary purposes this mean value is sufficiently accurate since there is always some error in [illegible] by [illegible] the average [illegible] of each air card. Table 15 gives the results of these computations. Because the [illegible] only for numbers one and [illegible] for the remainder of the [illegible], and the air was consequently not heated so much, the thermal efficiency is much larger [illegible] with the [illegible]. [illegible] thermal efficiency [illegible] that the valves do not always work as well as they should. Part of the time some of the valves did not open at all. [illegible] the inlet and [illegible] valves are placed in the compressor heads thus making the jacket water [illegible] when the highest point of pressure is reached and [illegible].

The [illegible] water pumped when the compressor was [illegible] three wells can only be estimated, as only one well was measured. About [illegible] feet of vertical pipe was added to well number two in order to reach the measuring tank. This makes a little difference in the conditions in which the three wells worked. Again well number [illegible] was nearest the air receiver, number three next, and

Table 13.

Mean Effective Pressure and [illegible] of Air Cards if

Isothermal Compression were Followed.

[illegible]	[illegible]	[illegible]	Effective [illegible]	Isothermal [illegible]	Thermal Efficiency.
1	[illegible]	.29	15.[illegible]	7.35	[illegible]
[illegible]	[illegible]			[illegible].47	[illegible].4[illegible]
[illegible]	[illegible]			[illegible].04	[illegible]
[illegible]	[illegible]			7.[illegible]	[illegible]
	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]			.[illegible]	[illegible]
	[illegible]			[illegible]	[illegible]
	4[illegible]			[illegible]	[illegible]
	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
	5[illegible]			[illegible]	[illegible]
[illegible]	[illegible]			[illegible]	[illegible]
[illegible]	[illegible]			[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
	[illegible]			[illegible]	[illegible]
	[illegible]			[illegible]	[illegible]
	[illegible]			5.77	[illegible]
	58	.2[illegible]	15.2	5.34	[illegible]
Average	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

Note.—The thermal efficiency is the ratio between the [illegible] of the cylinder cards, for one revolution, if isothermal compression were followed and the actual [illegible] of the same [illegible] for the same time.

[illegible] furthest away, so that the air pressure at the wells was not the same, on account of the loss through friction in the pipes. Number two threw the most water, number three the next [illegible] amount and number one less than number three. It has been estimated that under ordinary conditions numbers one and three [illegible] will throw not more than one and one half times as much [illegible] number two, probably less than this amount. During the [illegible] hours number two raised 16,593.4 gallons of water [illegible] gallons per day. At the rate given above the three wells [illegible] 248,903.5 gallons per twenty four hours. This is 867.1 gallons of water raised per H.P. per hour, or 55.5 pounds of water raised per pound of steam. This is no better than the results [illegible] from some "deck" deep well pump [illegible], [illegible].

From the results obtained it will be seen that the air lift at [illegible] not [illegible] the claims of the advocates of this system [illegible] pumping. This is due partly to the [illegible], and also to the fact that the wells are not adapted [illegible] successful operation of the system. The chief reason for [illegible] is that the depth of the water in the wells is not [illegible] great enough for the height the water has to be lifted.

[illegible] A New Method of Compressing Air.

134 : 137 (5p. [illegible]) J. P. Frizell.

[illegible]

[illegible] Experiments on the Compression of Air by the

111 : 145 Direct Action of Water.

[illegible] (11p. 4d. 2t.) J. P. Frizell.

[illegible] The Air Lift Pump.

[illegible] (3p. 3d. 1t.)

[illegible] Historical. Gives results of tests made by

Prof. P. M. Randall at Alameda, California.

[illegible] Pohle's Air Lift.

[illegible] ([illegible])

[illegible] Notice of paper by R.E.Brown and Hans Behr.

[illegible]

[illegible] Dr. Pohle's Air Lift Pump.

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[illegible] H. C. Behr.

[illegible]

[illegible]

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[illegible]

J. [illegible]	The Theory of the Air Lift Pump.
[illegible]	(2[illegible]p. [illegible]. 1t.) Prof. [illegible]. [illegible]. Harris.
[illegible]	
T.A [illegible]	Pohle's Air Lift Pump.
4[illegible] : 566	(1-1/3p. 4l.) C. A. Stetefeldt.
[illegible]	
[illegible]	The Air Lift Pump.
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[illegible]	Prof. F.Josse in th[illegible]
[illegible]	(1p. 5c) "Zeitschrift".
[illegible]	
[illegible]	The Air Lift Pump.
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[illegible]	Report of test at Rockford, Ill.
[illegible]	The New Rockford Pumping Plant.
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[illegible]	Raising Water by the Air Lift.
[illegible]	
[illegible]	
[illegible]	
[illegible] : 64[illegible]	
[illegible]	
[illegible]	Raising Water by the Air Lift.
[illegible]	(1p. 2i.)
[illegible]	Plants at Rockford and Joliet, Ill.
[illegible]	A Test of the Pohle Air Lift Pump
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[illegible]	(2/3p. 2d.) I. R. Merriam.
[illegible]	Air Compressor, Dixon, Ill.,
[illegible]	Water Works.
[illegible]	(1/2p. 1i.)
[illegible]	Water Works at Dixon,Illinois.
[illegible]	(1p. 1i.)
[illegible]	Air Lift used.
[illegible]	[illegible]
[illegible]	[illegible]
[illegible]	[illegible]
	[illegible]
[illegible]	[illegible] air [illegible].
[illegible]	[illegible]
[illegible]	[illegible]

C. A. 4 : 598 March '99	Improved Pneumatic Displacement Pumps. (2-1/2p. 4i.) Merrill Pneumatic Pump.
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C. A. 3 : 580 Feb. '99.	Driving Pump by Compressed Air. (6p. 6t.) William Cox. Gives formulae for finding amount of air required to raise a given amount of water when using direct acting pumps.